Animal education

An experimental study on the psychical development of the white rat, correlated with the growth of its nervous system

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ANIMAL EDUCATION

AN EXPERIMENTAL STUDY ON

THE PSYCHICAL DEVELOPMENT OF THE WHITE RAT, CORRELATED WITH THE GROWTH OF ITS NERVOUS SYSTEM

BY

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PART I.

An Experimental Study on the Psychical Development of the White Rat.

I. Introduction.

II. Preliminary Experiments.

III. Comparison of the Psychical Development of the White Rat at Different Ages.

IV. The Lower Stages of Memory.

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I. INTRODUCTION.

In the fall of 1901 the writer undertook, at the suggestion of Professors Angell and Donaldson, of the University of Chicago, to make a study of the psychical development of the white rat in correlation with the growth of its nervous system.

The object in undertaking such a problem was to throw some light upon the following questions: (1) How far is it possible (dealing with the psychological side of the problem) to give a systematic account of the gradual unfolding of the associative processes in the rat? (2) Is it possible (by a study of the nervous system of the rat) to find out whether or not medullated nerve fibers in the cortex of the rat are a *conditio sine qua non* of the rat's forming and retaining definite associations? (3) Is there any demonstrable connection between the increasing complexity of the psychical life, as manifested in the ability of the rat to form increasingly complex associations, and the number of the medullated fibers in the cortex, together with their extension toward its surface?

The method chosen for the investigation of this problem was as follows: The psychical life of the rat at different ages was studied, and the results of this investigation were then compared with the results obtained from a like study of the psychical life of the adult rat. By means of this comparison between the capabilities of the adult rat and the capabilities of the young rat we were enabled to state approximately when the young rat reached psychical maturity.

A systematic study of the development of medullation in the central nervous system of the rat was then begun. This study of the medullation process had for its object, incidentally, the determination of the first appearance of medullation in the cord, and the development of the medullated systems in the cord; specifically, the first appearance of medullation in the cortex, the

amount of medullation in the cortex at different ages, the extension of the medullated fibers toward the surface of the cortex, the difference between the adult rat and the young rat, which has just reached psychical maturity, in the amount of medullation in the cortex and the extension of the medullated fibers toward the surface of the cortex.

Flechsig in studies of the human cortex and the cortices of the higher mammals attempted to explain the significance of the great mass of fibers that are found in the cortices of the higher mammals. We may briefly summarize his conclusions. The cortices of the human and the higher mammals are divided into two great areas: (1) the area embracing all the regions of the cortex bound to the lower nervous centers by fibers of projection (pyramidal fibers, etc.)—the area of the centers of projection or the "sensory spheres;" (2) the area embracing all parts of the cortex lacking projection fibers, but connected with these sensory spheres by numerous fibers of association (fibers that do not leave the cortex, but unite the various portions of the cortex to one another). This constitutes the area of the "centers of association."

The centers of projection which by means of the lower centers control the peripheral nervous system are supposed by Flechsig to form the great reflex apparatus of the nervous system. These projection centers are supposed to enable the animal to realize its instinctive life; in other words, the "centers of projection preside over the animal life." These centers of projection exist in all mammals, even sometimes better developed than in man. The centers of association, on the contrary, lose considerably as we go down the mammalian scale, finally disappearing completely in rodents. The centers of association are little developed in carnivora, are equal in area to the centers of projection in monkeys, and finally in man reach their maximum growth and become of the highest importance.

That which characterizes the centers of association is their independence of the sub-cortical gray masses. They are lacking in projection fibers; but these centers of association are in con-

nection with the sensory spheres by pathways conducting in both directions. One pathway carries impulses from the sensory spheres to the centers of association. These impulses leave an ineffaceable imprint in the centers of association, which makes memory possible. "It is in these centers of association that psychical activity finds the elements of all our intellectual life. In these centers is the substratum of all human experience, knowledge, language, sentiments, and morals."

My purpose in undertaking the present work was to see how far the theory of Flechsig would hold in the case of the white rat and to attempt, if possible, a correlation between the increasing complexity of the psychical life of this animal and the increasing number of medullated fibers in its central nervous system.

Whether or not Flechsig is right in denying that centers of associations are present in the cortex of the rat can be answered only after a more complete study of the brain of that animal.

While I do not desire to criticise here the view of Flechsig, there is one fact worth mentioning now, leaving a further discussion of his view to Part III of this investigation. Flechsig denies, as has already been mentioned, that centers of association are present in the cortex of rodents. He admits their presence in dogs, cats, monkeys, etc. Now, if after a study of Small's report on the associative processes in the rat and the results set down in the present paper, one is convinced that rodents are capable of forming and retaining associations comparable and not greatly inferior to associations formed by dogs, cats, and monkeys (*cf.* Thorndike's study of those animals), it would appear that the theory of Flechsig has assumed for the associative processes of the higher mammals a neural mechanism more complicated than is necessary. If, without possessing centers of association, an animal, as low in the mammalian scale as the white rat is, can form definite associations that are comparable to those of an animal which stands higher in the scale and does possess such centers, then it appears that we need not assume that centers of associations are an indispensable condition in the formation of such associations.

However, it must be admitted that all the associations which have been formed by rodents—at least all those that have been reported—have been formed by means of one receptive center only—that of smell—while it has been shown that in cats, dogs, and monkeys the centers for vision and hearing play no inconsiderable part in the formation of associations by those animals. If the rat is capable of forming associations involving *only one receptive center*—that of smell—we should have to admit that the brain of the rat is a much simpler affair than the brain of the cat or the dog. But, in the opinion of the writer (supported, however, by but few experiments), the rat is capable of forming associations through vision, hearing, and through the temperature sense as well.[1]

The first part of the present paper deals with the psychical development of the white rat. It embodies an attempt to state the kind of problems suited to the associative abiliy of the rat and the complexity of such problems. It deals, furthermore, with the very early stages of memory and the approximate age at which a young rat is first able to solve a problem that apparently requires all the fundamental associative processes exhibited by the adult rat. Hand in hand with this part of the work will go the comparison of the psychical development of the rat at different ages.

The method of determining the psychical development of the young rat was like that of Small, Thorndike, and others in their studies on the associative processes in animals. The rats were made hungry, and food was then placed before them inside of some form of problem box. The general behavior of the rat in performing the act necessary to obtain the food was then noted. Besides keeping a record of their general behavior, a time record of the first, second, etc., successes was kept. The general behavior, time record, etc., of the various groups of rats were then compared with one another, and general conclusions drawn.

The experiments in this paper were conducted like those of

[1] When this investigation was begun, it was the purpose of the writer to carry out some experiments to decide this question, but, for the present at least, the lack of time prevents this.

Small, with one exception: Small, if I understand him rightly, allowed the rats to solve the problem only once each day. After each solution the rat was allowed to satisfy its hunger fully with the food contained in the problem box. Small criticises very severely the method of repeating the same experiment in quick succession: "To establish an association train, of which the motive and first term is hunger, and the end and last term is satisfaction of hunger, the train ought to be completely realized each time." Small is possibly applying here somewhat too much of his own conscious processes to the associative powers of the rat. If the rat is successful in overcoming the difficulties keeping it from the food, and is allowed to eat of the food for a short time, both terms of the "association train" are completed and the rat is instantly ready to repeat the same procedure until his hunger is fully satisfied. Such was certainly the case with my rats. That the rat does not reason, "I was not allowed fully to satisfy my hunger when I went to the food just now; therefore I really do not care to make the effort a second time," Small's careful work on the mental processes of the rat abundantly shows.

The order of procedure in my experiments was as follows: After solving the problem at hand the first time the rat was allowed to eat of the food for an instant, then he was at once given the same problem over again. By this method the rat had the opportunity of immediately putting into practice what he had learned from the first success. Whereas, if the problem had been given only once each day (before the association had been completely set up), the rat would have run the risk of losing the immediate benefit of his first success.

It might be well to mention here that there appears to be a difference between the rats used by Small and the rats used in the following experiments. Small states that his rats were timid and flighty. The rats used in the experiments reported in the present paper were raised by the writer in the laboratory and were exceedingly tame, as shown by the fact that they were not disturbed by handling and at once investigated all new objects in their neighborhood.

Coming now to the literature bearing upon this paper, for convenience I shall discuss it briefly under two heads: (1) that dealing with the associative processes in animals in general; (2) that dealing specifically with the associative processes in rodents.

1. Thorndike[1] remarks that there are two methods of investigating animal intelligence—the method of analyzing anecdotes and the experimental method.

The older investigators upon animal intelligence (Romanes and a host of others) sat in their offices and received letters from all parts of the country telling of some brilliant trick of a pet animal that could be explained upon no other ground than that of "reason." This kind of observer, after collecting numerous statistics of this nature, sat down at once and wrote a eulogy upon animal intelligence in general. Thorndike has aptly remarked that such a method gives us a "super-normal psychology of animals."

The experimental method in comparative psychology has given us some true insight into the nature of the associative processes in animals. Lloyd Morgan separated himself from the anecdotal school and began the method of watching the formation of associations, rather than taking them already formed.

Summarizing briefly Morgan's views, we note the following points: Animals form associations, from the simplest to the most complex, by the method of trial and error. Animals are capable of forming associations in line with their "inherent abilities." The animal comes into the world endowed with certain structures which make the formation of certain associations easy. If the neural and motor adjustments are perfect at birth, we have the mechanism of pure instinct. Intelligence in such cases would be useless luxury. But the mechanism for most instinctive acts is not so perfected at birth. In this case "intelligence comes in to guide the activities to individually adaptive results, through the association of ideas and the control of motor responses." [2]

[1] *Animal Intelligence*, p. 5.

[2] *Introduction to Comparative Psychology*.

The following three sentences[1] I think state clearly Morgan's views as regards reasoning in animals:

We must now take up the subject where we left it at the close of the sixteenth chapter, in which I contended that a very large percentage of the activities of animals may be fairly explained as due to intelligent adaptation through association founded on sense experience. I freely admit that there is a small—in my opinion very small—outstanding percentage of cases, the explanation of which seems to involve the attribution to animals of powers of perception and of rational thought. But seeing the smallness of the number of the cases of this type, and seeing the anecdotal character of the record, it is, in my opinion—an opinion which I shall have no hesitation in changing, if the results of systematic investigation and carefully conducted experimental observations warrant my so doing—that, were all the circumstances known, this outstanding percentage would disappear, and that the whole range of animal activities would be explicable as the result of intelligent adaptation.

In the above statements Morgan is in harmony with the other contemporary psychologists. But he finally concludes that associations in animals are much like associations in man. "Nine-tenths, at least, of the actions of the average man are intelligent, not rational. Is it any injustice to the brute to contend that their inferences are of the same order as those of the excellent practical folk?" [2]

Thorndike criticises Morgan justly, I think, in drawing the conclusion that associations in animals are at all comparable to the great number of associations that we find even in these "excellent practical folk":

Association in animals does not equal association in man; the latter is built over and permeated and transformed by inference and judgment and comparison; it includes imitation in its narrow sense of transferred association; it obtains where no impulse is included; it then takes frequently the form of long trains of thought ending in no pleasure-giving act; its elements are often loose, existing independently of the particular association; the association is not only thought, but at the same time is thought about.

Thorndike holds that only a few associations in man are at all comparable to associations in animals. Associations that one

[1] From chap. xx of MORGAN'S *Introduction to Comparative Psychology.*

[2] *Animal Intelligence*, p. 376.

forms while learning to swim, to juggle, to play tennis, etc., are comparable to associations that are formed by animals, "provided that we remove in the case of the man all the accompanying mentality which is not directly concerned in learning the feat." In such associations as the above we have contained desire, sense impression, impulse to act, and possible representation. These are supposed by Thorndike to be the elements in the formation of associations by animals.

2. Turning to the associative processes in rodents, the work of Small[1] is especially noteworthy. His experiments on adult white rats (a few also upon the wild gray rats) extend over a period of nearly two years. His method of conducting experiments upon the rats has already been noted.

Since the experiments reported in the present paper are analogous to those conducted by Small, it would be useless for me to go into his work except in the briefest way. The results of Small's study harmonize with the results of other recent investigations on the mental processes in animals.

The most significant points bearing upon the present problem may be very briefly summarized. The rat is capable of forming and retaining definite associations. The complexity of such associations is comparable to the complexity of the associations formed by dogs, cats, and chicks. Rats in forming associations do not imitate except in the simplest way (scratching where others scratch, etc.). They do not learn by being put through an act. Their method of learning is a gradual selection of certain acts and movements in the given situation by reason of the satisfaction they bring.[2] Associations in the rat are gradually formed. The first success in solving a problem is always longer than the second, and the time, when once the trick is learned, is rapidly diminished until the movement becomes practically a reflex.

From this discussion of the literature we see that there is some difference of opinion among the writers of comparative psy-

[1] *American Journal of Psychology*, Vol. XI, No. 2; *ibid.*, Vol. XII, No. 2.

[2] Small's labyrinth test is supposed by him to be a possible exception to this simple procedure.

chology in regard to the analogy that can be drawn between associations in animals and associations in man. The part that imitation may play in the formation of associations and the degree of complexity of the relations which animals perceive in performing certain acts are other points of dispute. It is not necessary in the present paper to go into a further discussion of these points of difference. All writers agree that rats can form and retain associations. This paper presents a study of the formation of such associations. The value of these for the present problem remains unchanged, no matter what relationship may ultimately be found to obtain between human and animal association.

II. PRELIMINARY EXPERIMENTS.

November 19.—The apparatus used in this first series of tests was a cubical wire box about five inches on the edge, the wire used on the sides being of one-eighth inch mesh. The floor of the cage was of wood, and this floor had two parallel strips of wood tacked across the lower surface of the bottom, one on each side. A hole large enough to admit the largest of these young rats was made in the floor near one edge.

The following photographs (Figs. 1 and 2) explain the construction of the box.

FIG. 1.

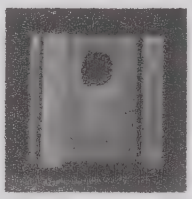

FIG. 2.

The stimulus used in these preliminary tests was soft light-bread. The method of conducting the experiment was to put this wire box containing the bread into a large empty cage. Sawdust was then banked up around the box so as completely to

conceal the entrances. The young rats were then taken from their living-cage and placed in the cage containing the box. A record of the time, and the movements made in performing the necessary acts to reach the food, was then made.

By comparing this method with that used by Small,[1] this difference will be found: Small put the box containing the food into the cage where the rats usually live. This method I did not adopt because the floor of the living-cage, in the case of my rats, was always well covered with straw, and this makes it very inconvenient to carry on a test where sawdust is used. Then the doors of the living-cages here are too small to admit the apparatus. The rats used in these experiments were all exceedingly tame. This of course made them lose all fear of handling. In none of these tests was there any evidence of fear except in rare cases, which are always noted.

Experiments were begun upon this date by giving this box for examination [2] to ten young rats supposedly about one month of age. Food was placed inside the box and they were allowed to enter the hole in the floor of the box without hindrance. All of the rats became interested at once and scrambled in one after the other in a very short time. This test was made simply to familiarize them with the box and to let them get used to getting food in this way.

November 20.—Straw was piled up around the box, and the rats were then tested to see if they could overcome a slight difficulty. This was done to give them a kind of graded series, first the box alone, next the box with the straw around the approaches, and then finally the regular sawdust test.

The straw gave them practically no difficulty at all. As soon as the rats were given the test they sniffed the food for an instant and then made a dash through the straw for the hole in the floor of the box.

November 21.—The regular sawdust test with Box I was given them today. (This test is directly comparable with that of

[1] *American Journal of Psychology*, Vol. XI, No. 2, p. 135.

[2] Hereafter called Box I.

Small; see reference cited above.) The rats were divided into two groups for today's work.

One from the first group dug the sawdust away in two or three strokes and entered the box in 3 min. The others in this group followed him in a short time.

The second group, when given the test, wandered aimlessly about for a few moments before beginning work. Finally one little fellow got the problem in hand and began digging vigorously and definitely on the right side. Time: 13.5 min. The others in this group soon ran around the box and entered where the successful one had made the hole.

November 22.—The rats were today temporarily divided into three groups containing four, three, and three rats respectively. The first group went earnestly to work, all of them scratching at the sawdust, but some working on sides where the strips were tacked across the floor. Finally two began scratching at opposite ends and entered in 2.5 min.

For the second group the time was the same.

One from the third group entered in 1.5 min.

November 24.—After these experiments had been carried thus far, it was found that four of these rats were sixty-three days old. For a time it was feared that this would vitiate the reliability of the results already obtained. So to avoid this the ten rats were tested individually. In this way it could be found out whether or not the four older ones had done all the work.

An interesting thing came out in this test which opened up a new line of investigation: while each rat successfully solved the problem of Box I, the time of the six young rats varied from 1 to 3 min., while that of the four older ones varied from 1 to 7 min.

On this same day the box was given for investigation to three young rats, twenty-five days of age. This group had been weaned only two days before, and so naturally they did not care much for bread. All of them, however, examined the box, and finally entered and nibbled at the bread.

November 24.—Today this group was given the regular sawdust problem. The first rat solved the problem in 4 min., the second in 7 min. The third rat did not make any attempt to solve it. An examination showed that his leg was broken. He was then removed from the group.

These preliminary tests, extending over five days, have brought out clearly that the associative processes have already begun in rats of the above ages. These tests were made simply to find out whether the young rats were as yet developed enough to form definite associations and to retain them. The object of the tests was not to get at an exact quantitative statement of the time involved in learning the problem, nor to find out individual differences as regards the quality of work.

As these tests have been carried on in practically an analogous way to Small's, perhaps a comparison of the results will illustrate a proposition I shall try to prove in this paper.

Average time of first entrance of adult rats.....85.50 min.
Average time of first entrance of young rats..... 6.87 min.

The average for the adult rats was obtained by taking the results from Group I, Series I and II, of Small.[1] The average for the young rats was taken from these preliminary experiments. This difference in time will be taken up more fully when I come to compare my own results obtained from the adult rats with the results obtained from the younger rats.

From these preliminary experiments two lines of work open up: Since the associative mechanism is at this age developed enough easily to overcome any difficulties of the kind already given these young rats, it is desirable to find out whether there are problems which can be solved by the adult rat, but which cannot be solved by the younger rats until the nervous system is more mature. Along this line of work attention will be paid to the rats of different ages in order to find out whether there are any progressive changes as regards activity, time of forming

[1] *American Journal of Psychology*, Vol. XI, No. 2, pp. 134-9.

a new association, definiteness of work after the association is formed, etc. In other words, this line of work will have for its object the comparison of the psychical development of rats at different ages.

The second line of work will be a study of what may be called the lower stages of memory in the white rat. Since at twenty-five days of age the rat shows every evidence of having advanced associative powers, there must be an earlier period when this ability to form definite associations is not present. The object of this part of the investigation will be to find just when the associative processes begin, as far as we are able to judge by laboratory tests. After we find by means of the first line of work certain definite problems which a mature rat can solve, then these problems will be given to younger and younger rats, until we reach a point where we can say that a rat still younger could not solve the problem.

III. COMPARISON OF THE PSYCHICAL DEVELOPMENT OF THE WHITE RAT AT DIFFERENT AGES.

November 26.—For this series of experiments the three groups of rats used in the preliminary tests were chosen. Group I consists of four rats sixty-three days of age; Group II contains five rats thirty days of age; Group III consists of two rats twenty-five days of age. In all the following experiments these groups will be used and the results compared among themselves. Finally the results obtained from these three groups will be compared with those obtained from an adult group.

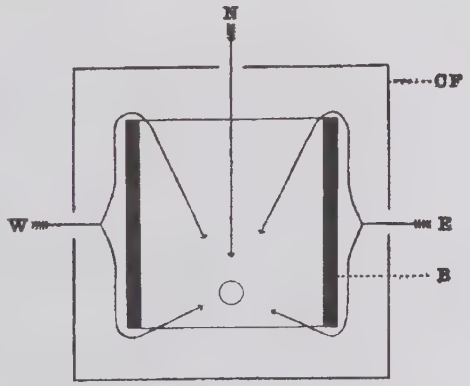

FIG. 3.

Actual experiments were begun by giving all three groups a complication of their previous problem. This complication was

made by putting a covered wire fence (C F, Fig. 3), 9 inches square, around Box I (B, Fig. 3). Three openings were cut in the north, east, and west sides of the fence (marked in Fig. 3, N, E, and W, respectively). The south side of the fence was left blank. The diagram (Fig. 3) explains the arrangement of the openings in the fence with reference to the hole in the floor of Box I.

EXPERIMENT I.

Three rats from Group II were first tried. These rats attacked the problem almost at once. They soon scratched through the entrances in the fence and seemed much puzzled when that failed to give them the food. Finally one rat began work on Box I and entered. Time, 3.5 min.

This successful rat was then given the task again. Time for fence, 0.75 min.; for Box I, 1.25 min.

The second three from this same group were then tried. Time: 2.25 min. for fence, 2.25 for Box I.

The rat successful in the last experiment was then tried again. Time: 1 min. for fence, 0.5 min. for Box I.

EXPERIMENT II.

Two rats from Group I were next tried. One rat solved the fence problem in 1.75 min.; the other one, in a different place, in 2 min. The first one entered the food box in 4.5 min.

The successful one was then tried again: time for fence, 0.75 min.; for Box I, 0.5 min.

The second two from the same group were then given the problem. Both solved the fence problem in 1 min. each, but lost time in entering Box I, solving it, however, in 15 min. and 13 min. respectively.

The one first successful in the last experiment was tried again. Time: 0.5 min. for fence; 0.5 min. for Box I.

EXPERIMENT III.

Group III was then tried. These rats did not act as though they were hungry. They worked leisurely for a while, but as they did not get at the food in a few strokes, gave up the task for

a time, then went to work again. Time for fence, 5 min. and 7 min. respectively. After entering the fence they lost a great amount of time running around Box I. Finally one entered in 15 min.; the other one simply followed in his track.

The successful one in this last test was then tried again. Time for fence, 0.33 min.; for Box 1, 0.5 min. This was by far the prettiest response yet made in this work. It was like a flash, not a falter, but with a dash he was at the fence, and with a few vigorous strokes was through and attacking the inner box.

November 27.—It was thought desirable to change the entrances in the above test and give the rats the same problem over again, getting each rat's individual record for the first and second trial. The following diagram (Fig. 4) shows the arrangement of the entrances.

EXPERIMENT I.

First rat from Group II: This rat went at his work eagerly, but exposed all three of the entrances in the fence before noticing them. Time for fence, 1 min. He was slow in entering Box I. Time for this, 2.75 min.

Second trial of the same rat: time for fence, 0.25 min.; for Box I, 0.50 min.

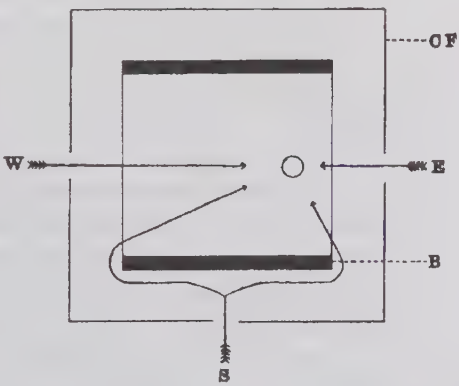

FIG. 4.

Second rat from Group II: This rat acted as the first one in regard to opening up the entrances in the fence. When he went in he began digging on the wrong side of the box. (It must be remembered that the sides of the box have been turned and it was possible yesterday to enter on the side where he first began digging.) Time for fence, 2.5 min.; Box I, 2.5 min.

Second trial: 0.75 min. for both fence and box together.

Third rat from Group II: It began digging at first at the side of the fence where there was no opening; finally it entered the fence and began digging on the wrong side of Box I. It continued digging on the wrong side of the box until the strip across the bottom of the box was exposed; then it began digging on the right side. Time: 1 min. for fence, 2 min. for Box I.

Second trial: 0.25 min. for fence, 0.50 for Box I.

Fourth rat from Group II: The actions of this rat were exactly the same as those of the third rat. Time for fence, 0.75 min.; for Box I, 4.75 min.

Second trial: 0.50 min. for fence, 0.75 min. for Box I.

Fifth rat from Group II: Strange to say, this rat showed some signs of fear. He soon lost this, however, and began digging on the wrong side of both fence and Box I, as the others had done. Time for fence, 0.50 min.; for Box I, 6 min.

Second trial: 0.25 min. for fence; 0.50 min. for Box I.

EXPERIMENT II.

First rat from Group III: This little fellow made short work of the fence, but dug on wrong side of Box I, as the rats of Group II had done. Time for fence, 0.50 min.; for Box I, 4.25 min.

Second trial: This time he went to the right place in both the fence and the box. Time for fence, 0.50 min.; for Box I, 0.75 min.

Second rat from Group III: This rat was almost a failure. At first he took no interest in his work, but walked around sniffing the air; every now and then he would change his occupation by squatting down and washing his face. Finally he strolled over to the fence and went to work. Time for fence, 9 min.; for Box I, 2 min.

Second trial: He entered the fence in 0.50 min., but lost time on Box I, but finally, after 9 min., entered it.

EXPERIMENT III.

First rat from Group I: When this rat was tried there was a great amount of noise made in the building by some workmen fitting steam-pipes. This caused the rat to show some signs of

fear and his attention was distracted. Time for fence, 4 min.; for Box I, 9 min.

Second trial: 1 min. for fence, 4 min. for Box I.

Second rat from Group I: It began work by scratching on right side, but missed the entrance, and then followed a whole series of useless movements. It would start to dig in one place, then leave it and feverishly begin at some other. It even went out in the open cage and dug there, but finally went back and entered. Time for fence, 1.50 min.; for Box I, 3 min.

Second trial, 0.75 min. for both together.

Third rat from Group I: The behavior of this rat was much like that of the preceding one. Time for fence, 7 min.; for Box I, 4 min.

Second trial: 3.50 min. for fence, 1.50 min. for Box I.

AVERAGE TIME OF ENTRANCES OF THE THREE GROUPS.

	Minutes.
Average time of first entrance of Group I, first day's experience	10.12
Average time of second entrance of Group I, first day's experience	1.12
Average time of first entrance of Group II, first day's experience	4.12
Average time of second entrance of Group II, first day's experience	1.75
Average time of first entrance of Group III, first day's experience	22.00
Average time of second entrance of Group III, first day's experience	0.83
Average time of first entrance of Group I, second day's experience	9.16
Average time of second entrance of Group I, second day's experience	3.75
Average time of first entrance of Group II, second day's experience	4.75
Average time of second entrance of Group II, second day's experience	0.85
Average time of first entrance of Group III, second day's experience	7.87
Average time of second entrance of Group III, second day's experience	5.37

The poor results obtained from Group III on their second test were due to the fact that the members of this group had been weaned only four days and a very little bread satisfied their immediate hunger.

A comparison of the records of the two other groups brings out the fact that the younger group consumed less time in making a first successful entrance. This difference in time was mentioned on p. 15 of this paper. *From the work already done it appears that a young rat will solve for the first time more quickly*

than a mature rat any problem conditioned on mere random activity—provided the younger rat has attained a development which will enable it to form the given association.

In order to bring this fact out more clearly, some form of test had to be devised which required for its solution activity rather than any advanced degree of associative ability. A simple labyrinth was thought to be the best form of test to meet this requirement.

EXPERIMENTS WITH A SIMPLE LABYRINTH.

December 2.—The diagram shown below explains the construction of the labyrinth used in the experiments immediately following.

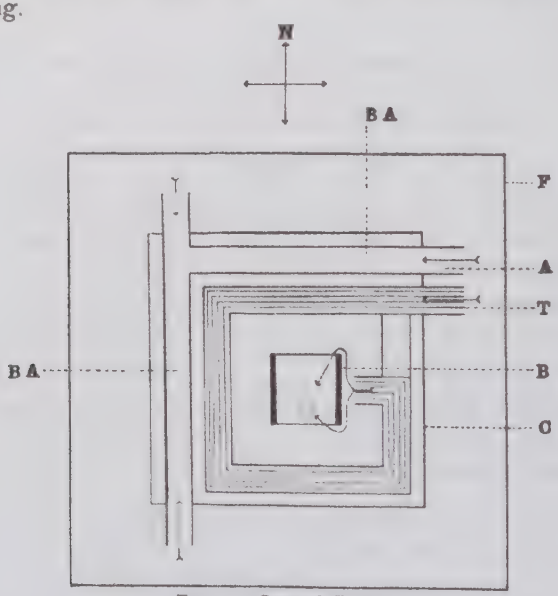

FIG. 5.—Ground Plan.

F, top of table, 4 ft. sq.
A, one entrance to blind alleys.
T, entrance to true pathway.
B, Box I.
C, covered wire fence.
BA, BA, blind alleys.

The material used in the construction of these pathways was cotton fire hose, the diameter of which was two inches—just large enough to admit the heaviest of these young rats.

A covered wire fence (C in diagram) extends around the whole labyrinth. The cotton tubing forming the pathways of the labyrinth projects from the sides of this fence for two inches.

The following photograph of a labyrinth used with the adult rats for this same work may explain the present one a little more clearly. The only difference between the labyrinth drawn here and the one in the photograph consists in the material used for the pathways. The pathways of the labyrinth shown in the photograph are made of pasteboard mailing tubes (three inches in diameter). With this exception the two labyrinths are identical.

FIG. 6.

From the diagram it is clear that a rat may enter the blinds in three places—north, south, and east. The true pathway has but one entrance (T, Fig. 5), and this is on the east side, very close to the opening of the blind which runs east—west (A, Fig. 5). This proximity of the true entrance and the entrance to the blind makes the association somewhat difficult. When the entrances are all covered with sawdust, this becomes an extremely pretty test, because it is then difficult to locate the true entrance, and when it comes to this place a rat is almost sure to open up the east blind (A) as well as the true entrance (T).

Box I was placed inside of the inclosure made by the fence, and in this box the food was placed. (All the openings of the labyrinth were uncovered.) A record for each rat for both a first and a second entrance is here recorded.

EXPERIMENT I.

A rat from Group II was first given this test. This rat ran frantically around, smelling at the food and clambering up the sides of the fence. This was the first time it had ever had to obtain its food without first removing sawdust from some entrance. At first the rat did not try the blinds, but tried to get in by every other means. It would run to the top of the fence and poke its nose through the meshes of the wire top covering the labyrinth, then clamber along down the sides, trying every corner of the structure. Before it had been at work fifteen minutes every seam and crack in the whole labyrinth had been tested with its claws and teeth. The movements of the rat are extremely rapid—too rapid to be recorded accurately. Finally, after everything else had been tried, it began chasing through the blinds and in a short time struck the true entrance and went to the food-box. Time: 20 min.

Second trial: Time: 4 min. There were many useless movements in this trial.

The second rat from Group II was then given the labyrinth. His movements were extremely rapid, and were much like those of the preceding rat, except that he began trying the blinds sooner. Time: 4 min.

Second trial: He ran at once to the true entrance before I could close the cage. Time: 0.25 min.

A third rat was then taken from the same group. It began work by running around the floor several times; then clambered to the top of the fence. It repeated this process of going from the floor of the cage to the top of the fence and back to the floor several times before trying the blinds. During its random movements it once stuck its head into the true entrance, but withdrew after entering a little way. Time: 9 min.

Second trial: It ran like a flash to the true entrance, but in its haste passed it, but came back and entered. Time: 1 min.

A fourth rat was then taken from Group II. This was an extremely vigorous rat, and its movements were almost frantic. So vigorously did it poke its nose under the covering of the fence

that it actually pryed up the cover and entered the inclosure in this way without having to take the ordinary journey to the food-box. It was, of course, immediately taken out and made to proceed with the more prosaic work of discovering the true entrance. Time: 22 min.

On the second trial it made a dash for the nearest opening, which happened to be a blind. Coming out, it hesitated for a moment, then went straight to the true entrance. Time: 1 min.

The last rat from Group II was then tried. The movements of this rat were of the same kind as those made by the rats in the preceding tests. It made fully as many useless movements. After working for about 30 min. it began to work more slowly, and for a time gave up the work, but later returned with renewed energy. Time: 1 hr.

Time for second trial: 1 min.

EXPERIMENT II.

The first rat from Group I was then tried, and as the movements and method of working of this rat are characteristic of the whole of Group I, I shall record his behavior in detail:

This rat did not go to work at once, but *walked* around the floor, lazily sniffing at the food. (All the rats of these three groups had been deprived of food for an equal length of time.) It then reared up on the fence and smelled at the food, then went to the top of the fence. Here it seemed to be content for a time, making only a few movements by trying to pry under the cover of the fence. Later it came down and poked its nose into the blinds, but never entered. At the end of 30 min. it was necessary to leave it at its task. On my return, 1½ hours later, I found it sitting on the fence, looking the picture of discouragement. Nothing would induce it to work any more.

Two other rats from this same group were then tested together, but they refused to try the blinds or show that desperate eagerness which the members of Group II had shown. They were by this time exceedingly hungry, not having been fed for over 30 hours. The smaller of the two rats once entered the blinds, but

soon gave up. Thinking the larger one might find difficulty in the passages, I put his nose in at the true entrance and made him enter. He found no difficulty whatever in going to the food. I then tried him again (alone), thinking that perhaps the memory of his compulsory passage would aid him in finding the way, but at the end of an hour no progress was made. I then took each rat separately, put him in at the true entrance, and made him go to the food.

I next put all three rats together into the cage. The smallest one went at once to the true entrance and went to the food. The two larger ones began trying the blinds, and finally one found the true entrance and went to the food. This seemed to wake up the third rat (he had been working at the problem for three hours), and he began to make some feverish movements, but failed to find the true entrance. Finally I put him in at the true entrance and repeated this three times until he could find the way himself.[1]

EXPERIMENT III.

The two little fellows of Group III were then tried. Their activity has wonderfully increased since the last tests were made with them. It is a pleasure to watch them fly from place to place, trying everything—a pleasure intensified after working for 4 or 5 hours with Group I. Time: 13 and 16 min. respectively.

Second trial: The one first successful dashed for the true entrance and entered in 0.75 min. The second one rushed about eagerly at first, but, not finding the true entrance, seemed at first to forget what it had to do. Time: 6 min.

Perhaps the most interesting thing appearing from this first day's work on the labyrinth is the number of useless movements made before the first success is achieved. I have recorded only a few of these, but the amount of time consumed before the true entrance is found is a fairly good index of them. This is particularly true of the youngest group, because they never cease their movements until the problem is solved. With the older

[1] The fourth rat from this group was not active on that day, so I did not try it.

groups this is not so nearly true, since at times they work intermittently and always slowly.

December 3.—Thinking it would be of interest to find out how these useless movements would be cut down by more experience with the same task, I gave the rats the problem over again today. The time record here will serve not only to show the lopping off of useless movements, but will also serve to give some idea of the definiteness of the association. If the association has been perfectly retained from their previous work, the time should be about equal to the time of the second entrance on that day. The following record shows that this was almost true.

EXPERIMENT I.

The first rat chosen was from Group II. It made many useless movements, chasing through the blinds and running over the fence, etc. Time: 5 min.

On the second trial it went at once to the true entrance. Time: 1.25 min.

The second rat from this group also lost time by running over the fence and through the blinds. Time: 2 min.

The second trial it made no useless movements. Time: 0.25 min.

The third rat from this group entered in 2.25 min. for his first entrance and in 1.75 for his second entrance.

The fourth rat from Group II entered the first time in 2 min. and the second time in 0.25 min.

The fifth rat entered in 2 min. for a first trial and in 0.16 min. for a second trial.

The last three rats all made useless movements on their first trial, but made practically none on their second trial.

EXPERIMENT II.

I next began work with Group I. I was a little curious to see how they would behave after yesterday's experience. The first one tried, walked about leisurely, then went straight to the true entrance. Time: 2 min. The second trial it reached the food in 1 min.

The next rat from Group I took only 0.50 min. to solve the problem the first time, but took 0.75 min. to enter the second time.

The third rat made a number of useless movements. Time for first entrance: 4 min. Time for second entrance: 4 min.

The fourth one from the same group was then tried. This rat was almost feverish in its movements. Time for first entrance: 7 min.; for the second entrance: 0.50 min.

EXPERIMENT III.

The two little fellows in Group III were then tried. Both of them raced like mad around the cage, then to the true entrance. Time: 0.50 and 0.75 min. Time for second trial: 0.18 and 0.16 min., respectively.

TABLE SHOWING AVERAGE TIME OF ENTRANCE OF THE THREE GROUPS FOR FIRST AND SECOND DAY'S EXPERIENCE.

Average time of first entrance, first day's experience, Group I	Failure
Average time of first entrance, first day's experience, Group II	23.00 min.
Average time of first entrance, first day's experience, Group III	14.50 min.
Average time of second entrance, first day's experience, Group I	Failure
Average time of second entrance, first day's experience, Group II	1.45 min.
Average time of second entrance, first day's experience, Group III	3.37 min.
Average time of first entrance, second day's experience, Group I	3.37 min.
Average time of first entrance, second day's experience, Group II	2.65 min.
Average time of first entrance, second day's experience, Group III	0.62 min.
Average time of second entrance, second day's experience, Group I	1.56 min.
Average time of second entrance, second day's experience, Group II	0.73 min.
Average time of second entrance, second day's experience, Group III	0.17 min.

The table shows that the youngest group, in every case, made the best record on the first entrance. This emphasizes very clearly the point I have been urging all through this paper.

Members of Group III seem now to be at the period of their greatest activity. When put face to face with a new situation, their movements are wonderfully rapid. In none of these tests have I ever seen these little fellows stop for any length of time until they obtained the food. Even when they are put back in their own cage they continue these movements. But in the

living cage this activity takes the form of play. Their conduct at this age reminds one very much of young children.

While the time for a first entrance, or a first success with any problem conditioned chiefly on activity, is apparently shortest in a group which has reached this stage of superabundant activity, it does not mean that the problem is accomplished with fewer useless movements. On the contrary, I think anyone who has watched rats work at this stage of their development will be convinced that they make more useless movements than rats which have passed this stage of development. But, owing to the extreme rapidity with which the movements are made, the time record is smaller.

A comparison of the time for the first entrance on the second day's experience with that for the second entrance on the first day's experience shows that, while the association was not perfectly retained, yet the loss is surprisingly small when we consider how few were the number of experiences the rats had had with this problem.

December 4.—The labyrinth was next complicated by piling sawdust 3 inches deep around all sides of the fence. This completely concealed all the entrances. Inside the inclosure, around Box I, sawdust was also heaped up, thus giving them, after getting into the true entrance and coming into the inclosure, the same problem they had previously solved in the preliminary tests (see p. 13).

This complication of the labyrinth makes an extremely pretty test for bringing out useless movements, and likewise for showing the rapidity with which these movements are discontinued when once the association is complete.

EXPERIMENT I.

Two rats from Group II were first put to work, and as their movements are characteristic I give the results here somewhat in detail. Both began scratching in the sawdust at once. Both buried their noses in it as far as possible, then rooted the sawdust away like a miniature snowplow. But, in contrast to the previ-

ous test with the labyrinth (where all entrances were uncovered), little time was consumed in running around the cage and up and down the top and sides of the fence. Finally one discovered the south blind and ran straight through and pushed away the sawdust from the north opening of the same blind. Coming out at the north and finding nothing but more sawdust, it chased back to the south opening again and repeated the procedure.

Meanwhile, the other rat discovered the east blind and chased about through all the systems of blinds, then came back and scratched for a time on the east side of the fence, and in so doing opened up the true entrance. He at once entered and came out at the food box and began scratching at the side nearest the opening of the tube; but this was the blind side of Box I, so he, of course, met with no success. Failing after a few strokes, he seemed to feel that he had not done the right thing. Accordingly, he turned and came out into the open cage. Very soon he retraced his steps, and this time worked upon Box I until he found the opening in the floor. The second rat then came to the true entrance and went to the food. Time for successful rat: 9 min.

I then tried the two rats independently. The rat successful in the previous test was first tried. This rat opened up all the blinds and scratched for a while along the sides of the fence. He entered finally, but lost time at Box I. Time: 5 min.

The rat unsuccessful in the first trial was then given the problem. Although he had scratched in the sawdust himself for a long time, and had had every opportunity to watch the successful one open up the true entrance, this experience seemed to be of no use to him. His movements were no better directed this time than in the first trial. Every blind was opened up, and nearly all the sawdust surrounding the sides of the fence was rooted and scratched away, before he succeeded. Time: 11 min.

I then tried him again. This time there was hardly a useless movement. Time: 1.50 min.

A third rat from the same group was tested in like manner. It opened up every blind and did much useless work on the sawdust around the fence. Time: 15.50 min.

On the second trial it made almost as many useless movements. It started out right, but failed to find the true entrance when it was scratching on the east side of the fence, so became confused. It even seemed to forget the association entirely. Time: 13.50 min. I tried him a third time, and after 5.50 min. he was successful.

The fourth and fifth rats from Group II worked desperately. Not satisfied with opening up all the blinds and tearing away all the sawdust from the fence, they bit and tore at its wires. They continued this even after the true entrance had been halfway exposed. Time: 23 and 28 min.

The second trial they worked more calmly, but still continued to scratch in wrong places. Time: 1.50 and 4 min., respectively.

EXPERIMENT II.

The two little fellows, members of Group III, went to work with all their might. Before they had been in five minutes I believe they covered every square inch of the cage. The blinds were all soon opened, and before the true entrance was found the sawdust was removed from the sides of the fence. Time: 12 and 13 min. Although their time was shorter than that of the older rats, fully as many useless movements were made.

They worked just as rapidly on the second trial. Many useless movements were likewise made in this trial. Time: 2 and 2 min., respectively.

EXPERIMENT III.

The first rat from Group I walked around the cage slowly before beginning to scratch. Although it made many useless movements, it scratched only along the east side. It did not enter a single blind. Time: 25 min.

On the second trial, however, it dug both on the north and west sides of the fence. Its work was exasperatingly slow. Time: 26 min.

The second rat from the same group was then tried. His work was slower than that of the preceding rat. He opened up all the blinds before finding the true entrance. Time: 60 min.

Second trial: Time: 5.50 min.

The third rat from this group worked slowly, but it made fewer useless movements. It opened up none of the blinds, but lost time smelling around and strolling about. After it found the true entrance, some time was lost at Box I. Time: 17 min.

The second trial it opened up the east blind and came out north; then went to the true entrance. Time: 2.50 min.

The last rat from this group opened up the blinds, but did not do so much useless digging around the sides of the fence. Time: 15 min.

The second trial it made a few useless movements. Time: 4.5 min.

TABLE SHOWING AVERAGE TIME OF THE FIRST AND SECOND ENTRANCES.

Average time of first entrance of Group I.....29.25 min.
Average time of first entrance of Group II.....17.30 min.
Average time of first entrance of Group III.....12.50 min.
Average time of second entrance of Group I..... 9.62 min.
Average time of second entrance of Group II..... 5.10 min.
Average time of second entrance of Group III.... 2.00 min.

The results from this test are practically identical, as regards showing the difference in the activity of the three groups, with those of the preceding test. Perhaps the contrast between the way in which the youngest group works and the way in which the oldest group works, comes out a little more clearly.

FURTHER TESTS FOR DETERMINING THE MENTAL DEVELOPMENT OF THESE THREE GROUPS OF YOUNG RATS.

Since all the problems that have as yet been given these rats have been solved with a rapidity that leaves no doubt as to their ability to overcome any problem of like difficulty, I determined to give them some form of problem not conditioned chiefly by activity, but demanding a higher kind of mental development. If now there are problems that an adult rat can solve, but which rats at the ages found in these three groups cannot, then this fact should appear in some form of problem which we usually think of as requiring for its solution an advanced stage of intelligence.

December 18.—The first form of test used with this object in

view was a food-box (Box II). The rat obtained entrance to this box by pushing up an ordinary latch. After the latch was pushed from its socket a spring opened the door. The following photographs should make the mechanism of this box clear.

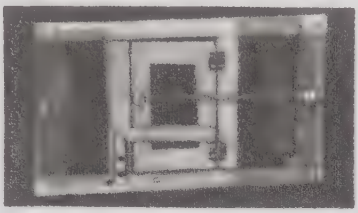

FIG. 7.

When the rats were put in the large cage containing this Box II, they would first run all around the cage; then their attention would be attracted first to the box, then to the door. Attention, I suppose, was finally attracted to the door because in running over the box and in nosing around it the door was necessarily moved slightly each time pressure was exerted upon it.

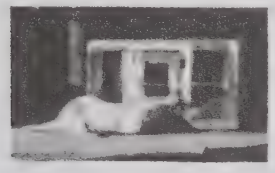

FIG. 8.

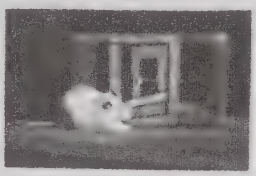

FIG. 9.

Considering the difficulty of forming such an association, I think the following time record is remarkable.

GROUP I.

1st rat:	time for first entrance.. 8.5 min.;	time for second entrance..2.00 min.
2d rat:	time for first entrance..18.0 min.;	time for second entrance..1.00 min.
3d rat:	time for first entrance.. 2.0 min.;	time for second entrance..0.25 min.
4th rat:	time for first entrance.. 4.0 min.;	time for second entrance..1.00 min.

GROUP II.

1st rat:	time for first entrance..16.0 min.;	time for second entrance..0.50 min.
2d rat:	time for first entrance..60.0 min.;	time for second entrance..1.00 min.
3d rat:	time for first entrance.. 6.0 min.;	time for second entrance..1.00 min.
4th rat:	time for first entrance..15.0 min.;	time for second entrance..1.50 min.
5th rat:	time for first entrance.. 8.0 min.;	time for second entrance..0.50 min.

GROUP III.

1st rat: time for first entrance.. 7.0 min.; time for second entrance..1.00 min.
2d rat: time for first entrance..12.0 min.; time for second entrance..2.00 min.

AVERAGE TIME OF A FIRST AND SECOND ENTRANCE OF THE THREE GROUPS.

Average time of first entrance, Group I..... 8.12 min.
Average time of first entrance, Group II.....21.00 min.
Average time of first entrance, Group III.... 9.50 min.
Average time of second entrance, Group I.... 1.06 min.
Average time of second entrance, Group II... 0.90 min.
Average time of second entrance, Group III.. 1.50 min.

In all the previous tests the oldest group of rats have had the poorest time record for a first success. A comparison of their time record in the present test shows that here this is completely reversed. This seems to bring out the fact that in the present test we are dealing with a problem which is conditioned upon direction of energy rather than upon a superabundance of activity not so well directed. If, when we come to the adult rats, the time for the solving of this problem is still materially less than that of the oldest of these three groups, we shall have good evidence that there exists a difference between the degree of development in the adult rat and rats of this age.

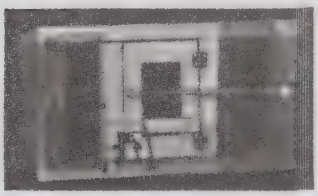

FIG. 10.

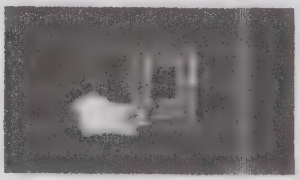

FIG. 11.

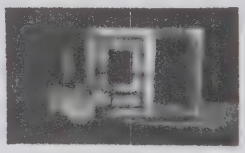

FIG. 12.

December 29.—After the association for opening Box II had been thoroughly established, I concluded to tie the latch and see what the rats would do. The experiment was conducted just as

the one on December 18, except that the latch was tied with a stout string. The three photographs explain how the latch was tied and the rat's procedure in overcoming this difficulty.

Two rats from Group I were first given this test. Both began at once to bite and tear at the door. They did not seem to understand why the latch did not yield when they struck it. So vigorously did they butt and push at the door that I feared it would be torn from its hinges. After many such useless movements one rat began gnawing at the string, but gave up before finishing his task. While this one was at work the other one came up and caught the string in his teeth, and pulled back upon it again and again. But as this failed to break the string he sat down and patiently gnawed the string in two. The instant this was completed he knocked up the latch with one blow of his nose and entered.

December 20.—This successful rat was tried again today with the same problem. Time: 0.50 min.; again in 1 min.

A rat from Group II was next tried. Time for first success: 12 min.; again in 1 min.; again in 0.16 min.

A rat from Group III was then put to work on this test. Time: 20 min., 2 min., 0.75 min., respectively.

It was not desired to let all the rats form this association, because I desired to give some of these rats tests involving the use of strings which were not to be gnawed.

The results obtained from this complication of Box II, although few in number, support those obtained from the preceding experiments on Box II. *The young rats do not seem to have reaped any advantage from their superior activity: mere activity appeared to have given place to a better direction of energy.* The discussion of this, however, will be continued when we come to compare the work of the adult rats with this work of the young groups.

The foregoing tests practically concluded the work of these three groups of young rats.

However, it must be remembered that one of the chief objects of this whole line of work was to determine how complex an association these young rats could form. With this object alone in view, two other problems were given them. Only a few tests were made, but enough to leave no doubt as to their ability to solve them.

January 1, 1902.—The first of these problems was a food-box

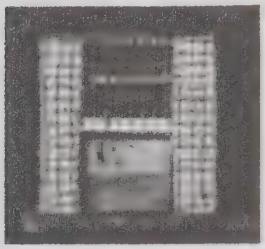

FIG. 13.

FIG. 14.

(Box III) much like Box II. This Box III had a latch inside that could be raised by a string which hung outside the door. The door was swung at the bottom and weighted at the top, so that when the string was pulled the latch was raised from its socket and the door fell in. The photographs show the construction of the box.

For this test two rats from Group II were tried. The knot on the string was first moistened with cheese. One rat opened the box in 12 min., 12 min., 3 min., 8 min., 2 min., 3 min., 0.33 min., 0.33 min., 0.16 min., 0.08 min., 0.08 min., respectively. All tests after this were almost instantaneous. A new string was then put on, one not smelling of the cheese. The association was definitely fixed, however, since he went in just as rapidly as before. This was the only rat from these groups that was tried. A problem of this kind, although the association cannot be formed in one trial, offers no insurmountable difficulty to rats of this age.

December 25.—The second form of problem with this same general purpose in view was a food-box (Box IV) about the same size as the preceding one, the entrance to which, however, was obtained upon an entirely different principle. The door and latch

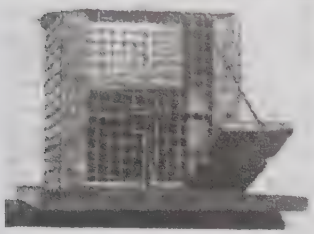

FIG. 15.

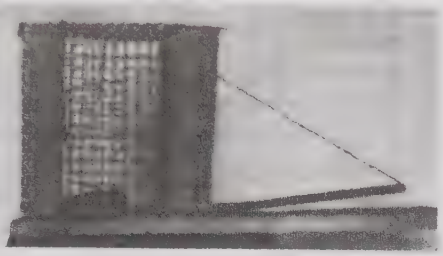

FIG. 16.

of this box were made just like the door and latch of Box III. From this latch a string extended over to an inclined plane which was placed back of the box, on the side opposite to the door. In order to open the door the rat must walk out to the end of the inclined plane, and as soon as his weight counterbalanced the fric-

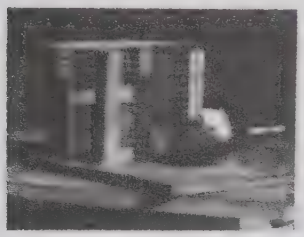

FIG. 17.

FIG. 18.

tion of the string and latch, the latch was drawn from its socket and the door was caused to fall in by means of a spring that was fastened to the top of the door at one end and to the floor of the box at the other. The four photographs explain the box and show the rat at work.

This is quite a complicated problem, and I must say I was extremely doubtful as to their solving it. However, I determined to give it a thorough trial.

A rat from Group II was first experimented upon. After five minutes of wandering he accidentally stepped upon the inclined plane out at the end, and the door fell in. He did not discover at once that the door was open. I waited until he did discover the fact, and after allowing him to eat for an instant, I tried him over again. When tried again *he went immediately to the door and tried to get in there.* After another five minutes he again stepped upon the plane. This time he seemed to be aware that the door was down, for he went at once to it. This happened again in two minutes, accidentally as before. This time, instead of going at once to the door, he looked eagerly under the trap, then trotted off to the door. When tried again he was as much at a loss as ever. This was repeated nine times more without any better results. After this he gave up the problem for that day.

December 26.—The same rat was tried on this problem again today. After twelve more accidental successes he associated the click of the falling plane with the opening of the door and would run at once to the food, but *he still failed to connect the falling of the plane with the necessity of walking out upon it.* After eighteen more trials he began to associate the elements of the whole thing, and in ten more trials he would press the plane down as fast as I could put him in.

There is one peculiar thing about his procedure after the association was formed: as soon as the plane fell he would go to the door in a certain way—turning always to his right. If he started to the left, he would become confused, and, even if he had gone half way around in that direction, would stop, return to the plane, then chase to the door turning toward his right. It was very amusing at times to watch his confusion.

SIMILAR EXPERIMENTS CONTINUED WITH ADULT RATS.

From the experiments with the three groups of immature rats we have just been considering we were led to believe that there existed a gradation in the degree of activity, beginning with the youngest group, which was most active, and ending with the oldest group, which was least active. It was thought desirable

to test this matter further by carrying on similar experiments with a group of adult rats.

Accordingly, all the apparatus was made large enough to admit full-grown rats.

For this work I chose four of the best-developed rats in the laboratory. Two of these rats were males and two females. The individual record of each rat was kept throughout these experiments. Reference to them will be made as follows: A=first male, B=first female, C=second male, D=second female.[1]

The four rats were kept together in a cage so that the odor of the group was the same. This precaution was thought necessary because it was feared that if a rat smelling of the odor of another group was put to work on a problem, then this foreign odor left around the various food-boxes might cause a delay in the work of a second rat of a different group.

It was thought desirable in these experiments with the adult rats not to depend upon a time record alone, but to note down how they work and the difference in the actual amount of the expenditure of energy between them and the immature group that we have just considered. This latter point will come out most clearly in the test with the sawdust-labyrinth, where the chances for useless movements are greatest.

These four rats were put in a freshly cleaned cage and allowed to go about fifty hours without food before actual experiments were begun.

February 22.—Experiments with Box I. (For a description of this test see p. 13.

Rat A was first tried. He did not begin work by tearing around the cage, as a young rat would do, but walked slowly to every corner and examined it. Next he began smelling at the food and clambering up the sides of the food-box. After he had been in 7 min., he scratched a few strokes, but this he did not continue. His movements are surprisingly slow. It takes this rat a long time to make up his mind to go up to or come down from

[1] These rats were approximately one year old.

the top of the box. If he happened to be on top of the food-box and wanted to come down, he would usually stretch his head down two or three times, then pull himself back, as though he feared to attempt so dangerous a feat. I have seen these full-grown rats do this for all four corners of a food-box. His first real work on the sawdust was begun on the side of the box where the strip is nailed to the bottom. He left this after he had exposed the strip, and began work in a place that would have brought him success had he continued work long enough. His next movements were made by crawling up and down the top and sides of the food-box. Although he kept this up for a time, his movements never became feverish. A younger rat would have gone up and down the food-box twenty-five times to this rat's five. He next began to scratch again, but this time indifferently as regards place. Finally he began to bite at the food, and in so doing trod down the sawdust around the entrance. After the entrance had been exposed for some time he finally noticed it and went to the food. Time: 53 min.

The second time he was tried he entered without a useless movement. Time: 1.50 min.

Rat B was at first more lively than rat A, but she soon quieted down and began digging in the sawdust. She left before accomplishing anything, however. Then followed a long period of waiting, with no movements of any kind. Finally, however, she waked up and began work again. Time: 83 min.

The second trial she clambered up on the box once or twice, then came down and scratched under. Time: 4 min.

Rat C was a little frightened when I first put him to work; nevertheless, he soon recovered and began work much like that of the preceding rats. After he had dug partly under the food-box, he came out, looked around, then stuck his head under, came out again, then put his whole body under, then began digging furiously, and later entered. Time: 13 min.

The second trial he opened up the box without a useless movement. Time: 0.75 min.

Rat D's work was just like that of the others. Time: 11 min. The second trial she made a few useless movements. Time: 2 min.

If we compare the average time of first success here with the average time of first success with the younger rats, we see that there is a tremendous difference.

Average time of first entrance of the group of young rats.... 6.88 min.
Average time of first entrance of adult group.....40.00 min.

Unfortunately I have no time record for the second entrance of any group of young rats. The average time of second entrance of this adult group was 2.06 minutes. This shows certainly a large decrease in time compared with the amount they took for a first entrance.

From the standpoint of mere observation I should say that in this test and in the following ones the adult rats made less than one-half as many useless movements as the immature rats.

February 24.—Experiments with the complication of Box I (see p. 17).

For this test the apparatus was arranged as is shown on p. 19.

Rat A made many useless movements, digging almost everywhere, but never spasmodically. Time: 11.5 min. The second trial he entered in 0.83 min.

Rat B tried to get in at first by prying at the cover of the fence. She came down soon and dug furiously on the east side, but stopped scratching before the entrance was disclosed. Then she stopped work for 38 min. Then she woke up and worked indifferently for 20 min. longer, finally giving up altogether. Thinking she was not hungry enough, I determined to starve her for another twenty-four hours. (The problem was left just as it was when she gave up.)

February 25.—I tried her again today. At first she would not scratch, but later she began scratching on the northwest corner of the fence. She left this and went east and almost completely opened up the entrance, but apparently did not notice

it. Seeing that she was about to give up again, I put her nose in the opening and made her go through. She lost some time in opening up Box I, but finally entered. Time: 70 min. The second entrance was completed in 4.5 min.

Rat C was not at all frightened today and began working quite vigorously for an adult rat. Time: 7.5 min. Time for second entrance: 6 min.

Rat D. Time for first entrance: 22 min. Time for second entrance: 3 min.

Average time of first entrance....27.50 min.
Average time of second entrance.. 3.58 min.

A comparison of this table with that on p. 21 shows again the great difference in the time of the first entrance of this group compared with the time of the first entrance of the young group. A comparison of the second entrance of the adult rats with the second entrance of the young rats does not show any wide difference in time.

February 26.—Tests with labyrinth. (For description and photograph of this labyrinth see pp. 22 and 23).

Rat A had been given very little food for a week now and was very hungry. I fed the rats only a very little each day during the whole series of experiments.) At first he spent his time upon the top of the fence surrounding the labyrinth, biting at the wires and poking his nose through the meshes. He spent fully ten minutes here, starting down at least four times, but each time seemed too frightened to make a determined effort to come down. Finally he mustered up sufficient courage to descend; then he strolled around the floor of the cage for a while. At first he did not notice the blinds at all, but later poked his nose into every one of them, including the true entrance, but he never offered to really enter one. After 45 min. he gave up the task and I put his nose into the true entrance and forced him in.

The second trial he was more active, really jumping from the fence to the floor. After trying the blinds once or twice, and

roosting on the cover of the fence for a while, he walked to the true entrance and went at once to the food. Time: 8 min.

The third trial he made a number of useless movements. Time: 6 min.

Rat B at first showed some reluctance to enter the blinds. Her work was much like that of the preceding rat. Time: 28 min. The second trial she made the trip in 2 min. Time for the third trial: 1.50 min.

Rat C wasted much of his time "holding down" the cover of the fence, as the other two rats had done. This rat worked more rapidly than either of the other rats had done. Time: .30 min. for a first entrance, 2.50 min. for a second, 0.5 min. for a third.

Rat D behaved much as the other three had done in regard to the time spent on the top of the fence. However, she did not try a single blind, but happened to enter the true entrance first. Time: 8 min. Time for a second entrance: 1.83 min.

Average time of first entrance of three successful rats (Rat A was a failure), 22 min.
Average time of second entrance of four successful rats, 3.58 min.

If this table is compared with the table found on p. 28, it will be seen that the time for the first entrance of the adult rats is not greater than that of the first entrance of Group II. In other words, the work of the adult rats was much better than the work done by Group I, since Group I for the first entrance on the first day's experience with the labyrinth were total failures.

February 27.—Second day's experience with the labyrinth. The purpose of this second day's work on the labyrinth was to find how well the association was retained from the previous day's work and to see whether useless movements were reduced to any great extent.

Rat A for first entrance.....5.00 min.
Rat A for second entrance.....1.12 min.
Rat B for first entrance.....1.00 min.
Rat B for second entrance.....0.50 min.
Rat C for first entrance.....1.50 min.

Rat C for second entrance.....0.50 min.
Rat D[1] for first entrance.....6.00 min.
Rat D[1] for second entrance.....5.00 min.

Average time of first entrance, second day's experience with labyrinth, 3.75 min.

Average time of second entrance, second day's experience with labyrinth, 1.78[2] min.

If we compare the first entrance of the second day's experience with the labyrinth with the second entrance of the first day's experience with the labyrinth, we shall see that the two time records are almost the same. This shows that the experience of the previous day was almost perfectly retained.

February 28.—The sawdust-labyrinth test with the adult rats.

Rat A began work by scratching away the sawdust along the west side, then along the north side, but did not continue in either place until the blinds were exposed. After 45 min. of very slow work he gave up the task. I left the problem just as he left it, and late in the afternoon of this same day I put him to work on it again. This time he was successful. Time for both working periods: 69 min.

Time of second trial: 2.5 min. On this trial he worked slowly but surely, *not opening up a single blind or scratching at any other place besides the true entrance.*

Rat B consumed an hour for her first success, but did not enter a single blind. The only other place she scratched besides the true entrance was a few strokes on the north side of the fence. Most of the time was spent in walking around and in sniffing the air.

On the second trial she did not make a single useless movement, but when she got ready walked straight to the true entrance and scratched in. Time: 3 min.

Rat C scratched in several places, but never entered a blind. Time: 16 min.

[1] She showed signs of extreme fear on second trial.

[2] If we neglect the second entrance of Rat D, who was certainly badly frightened on her second entrance, the average for the second entrance will be 0.70 min.

On the second trial he went immediately to the true entrance and scratched in. Time: 0.25 min.

Rat D began scratching at the middle of the east side of the fence and rooted away the sawdust up to the true entrance. She never tried to open up a blind. Time: 9 min.

On the second trial she went at once to the true entrance and scratched in, but she lost some time entering Box I. Time: 3.50 min.

Average time of first entrance.....38.50 min.
Average time of second entrance..... 2.31 min.

Again a comparison of this table with that on p. 32 shows that the time for a first entrance was much greater in the case of the adult rats than in the case of the young rats.

Attention must be called to the remarkable diminution of useless movements in the second trial—*not a single blind being entered*. This test, I think, brings out very clearly the superiority of the adult rat over the young rat in the matter of direction of energy.

February 29.—Test with Box II (p. 33).

This form of test will be the last one given these adult rats, since we can get no reliable time record for Box III and the box opening by means of an inclined plane (Box IV).

Rat A opened the latch in 11 min. When the door flew open he did not know what to make of it, but stood there and butted at the latch again before entering.

Second trial: time: 0.33 min. Time for third trial: 0.08 min.

Rat B was a total failure on this problem. After working 22 min. she gave up. I then let her in at the door, and after she had eaten for an instant, I tried her again. After this she seemed almost frantic. Within 3 min. she opened the door. I then tried her several times more, but could not get her to cut down her time, as a rat usually does. I do not understand why this rat should have acted in this way, unless she was so hungry she could not direct her movements normally.[1]

[1] The time of this rat will not be taken in making out the average time of entrance—not because it is bad, but because I opened the door for her, thus changing slightly the conditions of the problem.

Rat C began smelling of the food at the bottom of the door, and in suddenly raising her head knocked up the latch. Time: 2 min. Time of second trial: 0.25 min. Time of third trial: 0.08 min.

Rat D opened the latch in 2 min. for a first trial, in 0.08 min. for her second, and in 0.08 min. again for her third trial.

Average time of first entrance.....5.00 min.
Average time of second entrance.....0.22 min.
Average time of third entrance.....0.08 min.

Comparing the adult rats' work upon this test with the work of the young rats (p. 33), we find that the adult rats solved this problem in less than one-half the average time of the three groups of young rats. Furthermore, the average time for the second entrance of the adult rats was much less than the average time of any of the three groups of young rats for their second entrance.

This completes the comparative work on the four groups of rats.

It will be remembered that the purpose of this series of experiments upon the three groups of immature rats and the group of adult rats has been to test in a general way the psychical development of all four groups. In addition to this we hoped to find out both the nature of the problems which immature rats can solve and how great the complexity of such tests may be and still not be beyond the limit of their associative ability. If certain problems exist which the adult rat can solve, but which are too complex for the young rat, then we hoped to make this fact clear; failing in the search for such a problem, we hoped at least to reach some form of test which would make clear the characteristic differences between the associative activities of the adult rat and those of the immature rat.

While the problems given to these three groups of young rats do not by any means exhaust the number of associations that a rat can form, still these young rats have overcome a sufficient number of difficulties, and have overcome them quickly enough and definitely enough, so that we are led to believe that rats at the

ages found in these three groups can solve any problem that an adult rat can solve. In fact, if we had stopped experiments before coming to the test with Box II (box closed by an ordinary latch) and considered only the tests previous to that, conditioned mainly upon rapidity of movement, we should have been forced to conclude that the associative ability of the young rats (rats at the ages found in the three groups) is equal, or even superior, to that of the adult rats. But the moment we come to tasks requiring for their solution, not rapidity of movement, but direction of movement, we find that the adult rat is superior to the young rat.

In comparing in general, then, the work of the adult rats with the work of the immature rats, several facts come out quite clearly: Considering first a problem where mere activity is at a premium for its solution, we find that the adult rat consumes more time for a first solution than does a young rat, but that for a second solution this difference in favor of the immature rat is not so marked; indeed, the indications are that, if the time for a third, fourth, and several succeeding entrances were taken, the adult rat in his work would show a time record not only less than that of the young rat, but one that would be far more constant. This cutting down of the time of an adult rat for his third, fourth, and succeeding successes, below the time the young rat requires for his third, fourth, and later successes, would in all probability continue until the solving of the problem became a reflex action for both rats; then the young rat would again show the smaller time record, since his movements are more rapid than those of the adult rat.[1]

Considering next a problem not so conditioned upon activity —such as the test with Box II—we find that not only does the adult rat show a smaller time record for the second success, but that even the time for the *first success* is *much less* than is the time for the first success of any group of the young rats.

Perhaps the fact that comes out most clearly in the observation of the work of these four groups of rats is the one in regard to

[1] The test of these conclusions is reserved for future investigation.

the difference in the number of useless movements made by the young rats and those made by the adult rats. While the time is a good index of the number of useless movements made by a young rat at the period of its greatest activity, it is no index at all to the movements of an adult rat. As has been stated before, a young rat at its period of greatest activity almost never gives up a problem or stops in its work; with the adult rat such is not the case; the movements of the mature rat are slow, and, no matter how nearly starved he is, he never shows that feverish eagerness so often seen in the young rats. No quantitative expression of this difference in the number of useless movements made by the young and the adult rat has been found, and I can give only a rough guess. Certainly the young rat must make at least twice as many useless movements as the adult rat when both are put face to face with the same difficulties. The adult rat, too, cuts down the number of useless movements for succeeding trials far more rapidly than an immature rat.

SOME SUPPLEMENTARY TESTS ON THE INSTINCTS OF THE WHITE RAT.

In the above tests with the three groups of young rats certain questions came up relating to their instinctive life. In some of the tests, such as that of the labyrinth,[1] it was desirable to know whether or not these young rats showed a tendency to go into an entrance that another rat had just gone through.

From mere observation of the rats at work, it seemed to me that each discovered the entrances for himself independently of any rat that might have preceded him. For instance, I have seen one rat go into the true entrance, while another, coming up an instant later, would enter a blind opening situated near by the true entrance. In all these experiments I have seen the rats sniffing in the air, but it seemed to be at the food rather than at another rat's tracks. They very rarely stopped at an entrance to smell it, but if it suited their fancy would dash into it.

However, it must be remembered that rats have a keen sense

[1] P. 22.

of smell in detecting the odor of a strange rat when it enters their home. In the "rat quarters" at the University of Chicago we have a general runway where all the rats not kept in cages dwell harmoniously together; if a strange male rat is put in with these, the "boss rat" of the runway singles him out at once and "the best man wins."

The apparatus used for finding out whether or not rats track one another into entrances by the sense of smell was as follows: Four rectangular boxes, with wooden sides and wire netting at

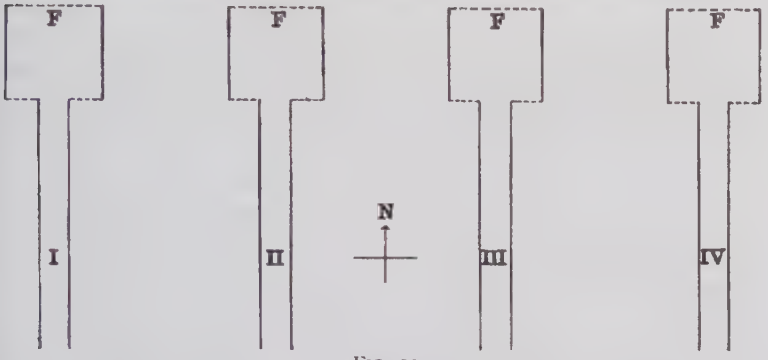

FIG. 19.

Tubes II and IV are kept always smelling of the rat odor. Tubes I and III are kept free from such odor. For the first test each rat from the three groups was put in at the south side of the cage containing the apparatus.

the two ends, were constructed. Through one of the wire ends of each box a pasteboard mailing tube, three inches in diameter, was admitted (marked by Roman numerals in Fig. 19). Strips of paper were then cut one inch longer than this mailing tube. These strips of paper were used to line the tube. The method of conducting the experiment was as follows: The tubes were all lined with paper; two of the tubes were kept always smelling of the odor of a rat and two were kept always free from any such odor. The two last-named tubes were kept free from the odor of the rat by changing the paper in them each time a rat entered. The stimulus used was fresh light-bread (F, Fig. 19). The four boxes were arranged side by side and a large cage was placed over all.

First rat from Group II, entered Tube II*[1]
Second " " " " " " I
Third " " " " " " II* came out and entered I
Fourth " " " " " " II*
Fifth " " " " " " III
First rat from Group III entered Tube II*
Second " " " " " " I
First rat from Group I entered Tube II*
Second " " " " " " I
Third " " " " " " II*
Fourth " " " " " " I

Thinking that the rats might be influenced by reason of their being put into the cage on the south side, I determined to test each rat four times, putting him in first west, then east, then north, and finally south.

	West	East	North	South
First rat from Group II entered.....	II*	IV*	I	III
Second " " " " "	III	IV*	II*	I
Third " " " " "	II*	IV*	II*	II*
Fourth " " " " "	I	II*	IV*+III	I
Fifth " " " " "	I	III+IV*	IV*	III
First rat from Group III entered	II*	III	II*	I
Second " " " " "	II*	IV*	IV*	I
First rat from Group I entered.....	I	IV*	III	II*+I
Second " " " " "	III	IV*	III	III
Third " " " " "	II*	II*	I+IV*	IV*
Fourth[2] " " " " "	IV*	IV*	IV*	IV*

Total number of tubes entered containing odor of rat.....34
Total number of tubes entered free from odor of rat.....28

This gives a balance of six out of sixty-two tests in favor of their tracking, which means that we have no good evidence for assuming that there is a tendency in these young rats to follow

[1] In the following tables the asterisk marks the tubes containing the rat odor.

[2] The fourth rat from Group I entered Tube IV every time he was tried. Thinking that he had perhaps associated the getting of the food by going into that particular tube, I took out the paper smelling of the rat odor and put fresh paper in its place, changing it each time he entered Tube IV. When put in on the west side, he entered IV, at the east side IV, at the north side IV, and at the south side III.

one another through entrances in the sense of tracking by the sense of smell.

In order that the above test might be made more conclusive, all four of the tubes were moistened at the entrance with damp sawdust. The damp sawdust retains the odor better than the dry paper. In the following test only Group II was used. The reason for this was that where different groups are used, differences in odor are left in the tubes: thus there was a possibility in the above test of the element of fear entering in. The odor of Group II is the same for all members of it, since they live in the same cage. To further eliminate any element of fear, each rat, just before experiments were begun with him, was rubbed around the entrances of the two tubes designed to be kept smelling of the odor of the rat. This procedure was repeated for each rat.

The arrangement of the apparatus was the same as on p. 49.

	West	South	East	North
First rat from Group II entered.....	I	I	I	I
Second " " " " "	I	IV*	IV*	IV*
Third " " " " "	I	IV*	III	IV*
Fourth " " " " "	I	II*	IV*	IV*
Fifth " " " " "	I	II*	IV*	IV*

The arrangement of the apparatus was then changed—I and III being kept "saturated" with the rat odor.

	West	South	East	North
First rat from Group II entered.....	IV	II	IV	I*
Second " " " " "	III*	IV	I*	I*
Third " " " " "	I*	IV	II	II
Fourth " " " " "	IV	IV	I*	II
Fifth " " " " "	IV	IV	II	III*

Total number of tubes entered smelling of rat's own odor.....18
Total number of tubes entered free from rat's own odor.....22

The results obtained from this test unquestionably support those obtained from the previous test.

It was thought worth while to continue this test with the four adult rats used in the experiments cited in this paper.

I determined to conduct this experiment a little more carefully than the preceding one had been conducted. Thinking that perhaps the element of sex would make the test more conclusive, I separated the males from the females for several days.

The males were then starved for two or three days, so that they would enter the tubes more quickly. The method of conducting this test was as follows: The four tubes were lined with paper, and damp sawdust was kept in the entrance. Two tubes, as in the preceding test, were kept smelling of the rat odor, but in this test the odor was always of a female.

The two tubes designed to contain the odor of the female were taken from the table, where the experiment was to be conducted, to the floor, and the female was then driven through them and rubbed around the entrance. This procedure was repeated after each test. The other two tubes were kept free from rat odor, just as in the previous test. After handling a rat the hands were always washed before picking up another.

In place of putting the rat into the cage at four different places, as was done on the test with the young rats, the position of the two tubes smelling of the rat odor was changed six times, while the rats were placed always in the center of the cage. In this table X and Y represent the two tubes that contain the rat odor.

Arrangement of Apparatus.	
I X Y IV	Male A entered IV; male B entered X.
I II X Y	Male A entered X; male B entered X.
X Y III IV	Male A entered IV; male B entered X.
X II III Y	Male A entered X; male B entered II.
X II Y IV	Male A entered X; male B entered X.
I X III Y	Male A entered X; Male B entered III.

Total number of tubes entered smelling of odor of female.....8
Total number of tubes entered free from odor of female.....4

The females were then tested in the same way.

I X Y IV	Female A entered Y; female B entered Y.
I II X Y	Female A entered X; female B entered II.

X Y III IV—Female A entered Y; female B entered Y.
X II III Y—Female A entered Y; female B entered X.
X II Y IV—Female A entered Y; female B entered Y.
I X III Y—Female A entered Y; female B entered Y.

Total number of tubes entered containing odor of male.....11
Total number of tubes entered free from odor of male..... 1
Total number of tubes entered containing odor of opposite sex.....19
Total number of tubes entered free from odor of opposite sex..... 5

We concluded from this test that adult rats show a preference for entrances that contain the odor of the opposite sex.

Another question that came up in the work of the rats was whether or not, other conditions being the same, they showed any preference between light and dark entrances. This question likewise arose from experiments with the labyrinth.[1] In this labyrinth the blind pathways are light, while the true pathway is dark.

Before I saw them at work on the labyrinth I would have said unhesitatingly that, if a rat showed any preference at all, it would have been for the dark entrances. Small animals in escaping from their pursuers instinctively seek some place to hide, and in the case of these rats, although perfectly domesticated, it was at least reasonable to suppose that they had not entirely lost this tendency.

To test this question, four boxes somewhat like those used in the previous experiment on tracking were constructed. The backs of two of these boxes were made opaque (A and B, Fig. 20); the backs of the other two were made of wire netting. In the middle of each of the four boxes a board partition was nailed. The front ends of all four boxes were made of wire netting. The pasteboard mailing tubes (I, A, III, and B in Fig. 20) were fitted both through the wire netting on the front end and through the partition in the middle of the box. We have each box, then, divided into two compartments, front and back. The front ends of all four boxes are exactly alike, but at the back end we have two of the boxes opaque and two that permit the entrance of light.

[1] P. 22.

Food (F, Fig. 20) was put into both compartments of each box. Since a rat was not permitted to see the backs of the four boxes, the front view of all four boxes appeared alike to him, *except that two of the tubes were light and two were dark.*

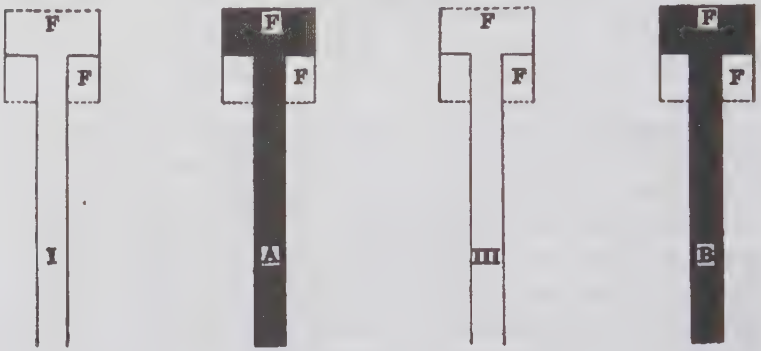

FIG. 20—Diagram of Apparatus.

In the following description of this test A and B show the position of the two dark entrances. The Roman numerals mark the position of the two light tubes. The position of the boxes was changed six times; the rats were put into the cage always at the same place.

Tubes arranged as in diagram.
1st rat from Group II entered tube III.
2d rat from Group II entered tube A, but came out at once.
3d rat from Group II entered tube I.
4th rat from Group II entered tube I.
5th rat from Group II entered tube I.

1st rat from Group III entered tube III.
2d rat from Group III entered tube I.

1st rat from Group I entered tube I.
2d rat from Group I entered tube A.
3d rat from Group I entered tube III.
4th rat from Group I entered tube III.

A II B IV—Arrangement for second trial.

1st rat from Group II entered tube II.
2d rat from Group II entered tube A, but brought out the bread.
3d rat from Group II entered tube A, but came out and entered II.

4th rat from Group II entered tube II.
5th rat from Group II entered tube B, but brought out the bread.

1st rat from Group III entered tube II.
2d rat from Group III entered tube B.

1st rat from Group I entered tube II.
2d rat from Group I entered tube II.
3d rat from Group I entered tube B.
4th rat from Group I entered tube IV.

A II III B—Arrangement for third trial.

1st rat from Group II entered tube A, but came out and entered II.
2d rat from Group II entered tube II.
3d rat from Group II entered tube II.
4th rat from Group II entered tube II.
5th rat from Group II entered tube A.

1st rat from Group III entered tube II.
2d rat from Group III entered tube B, but brought out the bread.

1st rat from Group I entered tube A.
2d rat from Group I entered tube II.
3d rat from Group I entered tube B.
4th rat from Group I entered tube B.

I A B IV—Arrangement for fourth trial.

1st rat from Group II entered tube A.
2d rat from Group II entered tube I.
3d rat from Group II entered tube I.
4th rat from Group II entered tube I.
5th rat from Group II entered tube I.

1st rat from Group III entered tube B, but came out and entered I.
2d rat from Group III entered tube B, but came out and entered I.

1st rat from Group I entered tube A.
2d rat from Group I entered tube B.
3d rat from Group I entered tube B.
4th rat from Group I entered tube IV.

A B III IV—Arrangement for fifth trial.

1st rat from Group II entered tube A.
2d rat from Group II entered tube III.
3d rat from Group II entered tube III.
4th rat from Group II entered tube III.
5th rat from Group II entered tube III.

1st rat from Group III entered tube III.
2d rat from Group III entered tube IV.

1st rat from Group I entered tube B.
2d rat from Group I entered tube III.
3d rat from Group I entered tube III.
4th rat from Group I entered tube A.

I II A B—Arrangement for sixth trial.

1st rat from Group II entered tube II.
2d rat from Group II entered tube I.
3d rat from Group II entered tube I.
4th rat from Group II entered tube I.
5th rat from Group I entered tube B.

1st rat from Group III entered tube I, then entered B.
2d rat from Group III entered tube I, then entered B.

1st rat from Group I entered tube I.
2d rat from Group I entered tube I.
3d rat from Group I entered tube A.
4th rat from Group I entered tube A.

Total number of dark tubes entered.....24
Total number of light tubes entered.....44

These results show that the young rats show a preference for light entrances. The young rats were used for this test because we have already shown that they do not track one another through entrances. If the adult rats had been used, tracking would doubtless have entered in, and the results of such a test as this would not have been so trustworthy as the present one.

WHICH DO RATS MAKE THE GREATER USE OF IN THEIR SEARCH FOR FOOD—SIGHT OR SMELL?

The following experiments are to test which of the two senses, sight or smell, a rat uses in his search for food when he is forced to use one rather than the other.

For this test two small wire boxes (A and B, Fig. 21) were made exactly alike. The mesh of the wire used in the construction of these boxes was large, and anything inside of the boxes could be plainly seen. An opening large enough to admit a rat was made in one of the sides, near the floor, of each box (E in Fig. 21).

Two sealed glass jars, filled with bread and cheese, were put inside one of the boxes (J J in Fig. 21 marks the position of the jars in the two boxes); in the other box two *empty glass jars,* exactly like those in the first box, were placed. The two boxes were then put eighteen inches apart and banked up with sawdust until the entrances to them were concealed. In conducting the experiment a rat was set down midway between the two boxes (at O, Fig. 21) and his choice was then recorded.

This experiment was expected to be merely preliminary to a succeeding test in which the rat would have to make a choice between sight and smell. I supposed that in the present test all the rats would at once choose the box containing the bread, which he could see, rather than enter the other box, which could offer him no inducement whatever—except perhaps a chance to gratify his inordinate curiosity.

The following is a diagram of the apparatus:

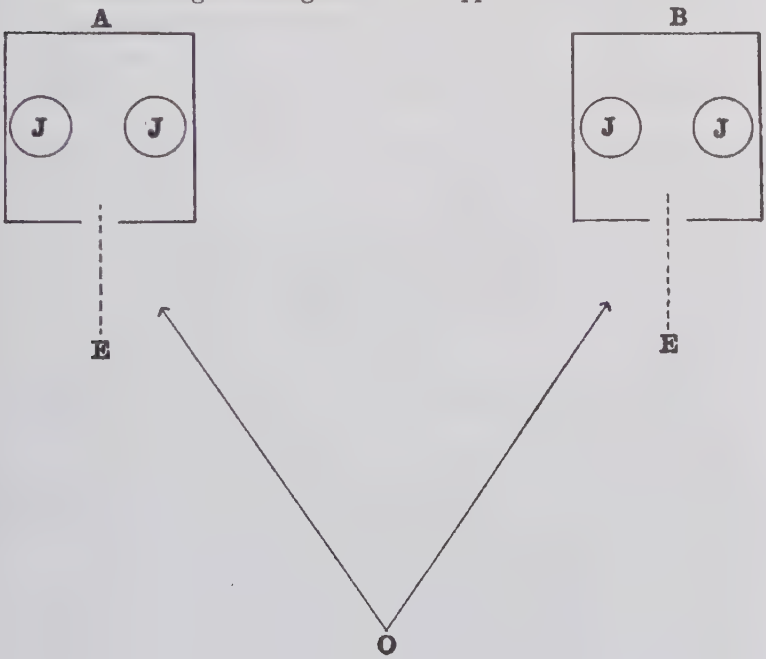

FIG. 21.

First rat from Group II: He went first to B and smelled at the box, then explored the large cage. He next went over to A, but seemed to take almost no interest in it, and soon went back to B. He next began a series of oscillations betwen the two boxes, dividing up his time about equally between the two. Finally he began digging at A, but left and dug a while at B; then came back and entered A.

Second rat from Group II: This rat at first showed no preference for either box, examining both, but finally scratched into A.

Third rat from Group II: This rat entered B after examining both.

The fourth rat from Group II entered B.

The fifth rat from Group II entered B also.

The two rats from Group III spent their time running from one to the other of the boxes, but entered neither of them.

Two rats from Group I were then tried. One entered B, and the other followed him. The other two rats from Group I were then tested. One opened up B at once, and the other followed.

From this preliminary test we learn that the mere sight of food attracts the rat but little.

A small piece of toasted cheese was then placed in B. This piece of cheese was lightly covered with sawdust, so that it could be smelled but not seen. The rats have now to choose between the sight of the food in Box A and the smell of the food in Box B.

The first rat from Group I scratched into B before I could close the large cage.

The second rat from Group I entered B.

The third rat from Group I entered B.

The fourth rat from Group I entered B.

The first rat from Group III entered B.

The second rat from Group III entered B.

The third rat from Group II entered B.

The second rat from Group II entered B.

The third rat from Group II entered B.

The fourth rat from Group II examined both boxes, but finally entered A.

The fifth rat from this group entered B.

This is good evidence that the rat in his search for food makes a greater use of the sense of smell than the sense of sight.

From these tests[1] we can conclude that the solution of the various problems which have been presented to the rats have been but little affected by instincts of tracking, etc. This is literally true for the young rats. The adult rats were probably aided in the labyrinth tests by the element of tracking.

In consideration of the fact that the true entrance to our labyrinth was dark, we may safely conclude that the average time of first entrance was, in all cases, greater than it would have been had the true entrance been light, but this does not at all affect the validity of the results which were obtained, since all the rats solved the problem under the same conditions.

IV. THE LOWER STAGES OF MEMORY.

On p. 16 of this paper we indicated the two lines of work which would be followed in this investigation of the psychical development of the white rat. We have already reported upon the first part of the work and obtained from it a series of "standard problems" in line with the associative ability of the rat. In determining this series of problems we began first with a simple test, such as having the rats find the entrance to a box, when the entrance had been concealed with sawdust, and ended with a complicated test, such as that of Box IV,[2] which required thirty or forty trials before the association was completely formed. It will be remembered also that we concluded from this line of work that the youngest group of rats experimented upon was sufficiently developed to solve any of these standard problems. In

[1] These results should be compared with SMALL, *American Journal of Psychology*, Vol. XII, No. 2.

[2] P. 37.

other words, we found that even in this youngest group of rats we were dealing with memory processes already well developed.

It now remains for us to experiment upon still younger groups of rats, with the purpose of determining the first appearance of the memory processes and their gradual development as manifested in the ability of the rat to form more and more complex associations.

In investigating the lower stages of the memory processes some form of test must be devised in which the mother can be used as a stimulus. This is necessary because no food other than the mother's milk will attract a rat before it is weaned. Even if rats before they are weaned could be made to seek the food that we ordinarily use as a stimulus, it would still be impossible at first to test them with any of the standard problems, because until they are fifteen or sixteen days old they have not attained a sufficient physical development to enable them to get in and out of boxes, etc.; nevertheless the memory processes, at least in their earliest stages, in all probability, have appeared before this degree of physical development is reached.

There remains for us to study, then, two periods in the development of the very young rat: The first period (A) coincides with the beginning of the memory process in the rat. During this time we shall find both the psychical and physical elements at a slow stage of development. The second period (B) takes up the study of the rat when the psychical and physical elements have attained a development just sufficient to enable the rat to solve the series of standard problems.

When we have found the earliest age at which the most complicated of these problems can be solved, then we shall be in a position to compare the medullation in the cortex of a rat of this age with the medullation in the cortex of the adult rat.

A. TESTS TO DETERMINE THE FIRST APPEARANCE OF THE MEMORY PROCESSES.

The following diagram and description explain the nature of the apparatus used to test experimentally the earliest manifestations of the associative processes.

A box (X, Fig. 22) was made in which the mother and young were kept throughout this part of the work. Two boards, *h* and *g*, 3 inches wide and 18 inches long, were nailed to the sides of Box X. Between these, two cross-slats were inserted, one 12 inches, the other 6 inches, from Box X, thus dividing the space into three compartments. Two holes 6 inches apart were then made in each of the two cross-slats. Two other holes similar to these were made in the sides of Box X (these holes were too small to allow the mother to pass through them). These openings are lettered in the diagram *a, c, e, b, d, f*.

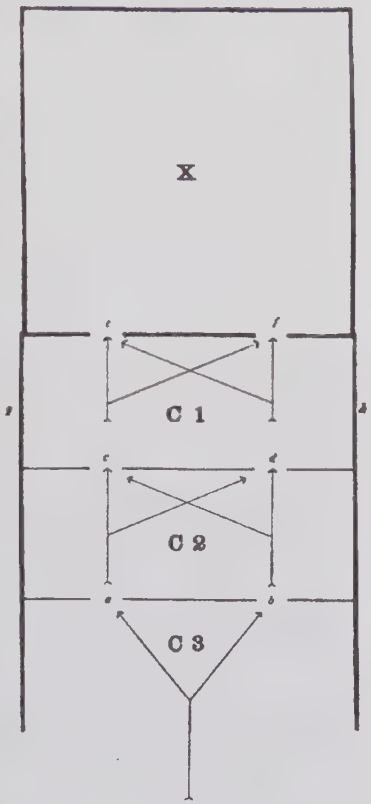

FIG. 22.

A glance at the drawing will show that the path back to the mother can be made either simple or complex.

The method of conducting tests with this apparatus was as follows: A baby rat was taken from its mother in Box X and put between some such openings as *a-b, c-d, e-f*. It was then allowed to make its way back to her. As soon as the young rats showed definitely their ability to go back when the pathway was simple, then the pathway was complicated by closing up certain of the entrances.

February 21 (ten days of age).—A gentle mother with a litter of seven young rats was put into Box X and allowed to "become at home" there. When the young rats were ten days old actual experiments were begun with them.

First test: A baby rat was put into compartment 1. It "nosed" around for a time until it came near enough for the mother to put out her head at one of the openings and grasp it in her mouth. She then gently drew the rat back and put it into the nest. I then put the young rat into compartment 2. It rubbed its way along the sides of the slats for 12 min., then went through *c* into compartment 1. The mother then began to make efforts to reach it, and finally she attracted it, probably by smell, and the young rat came toward her. The mother tried to grasp it, but failed; then the baby rat crawled off into one of the corners. Later, however, it passed nearer the opening, and the mother at once drew it in. I next tried it again by letting it start from compartment 2, as before. This time it entered *d*, then crawled over to *e*, where its mother had already twice received it. For a fourth trial I put this rat into compartment 3. It went back through *a* in a short time, but stopped in the corner near *c*. It stood there motionless for 4 min., then put its head in *c*, but withdrew it before entering. I could get this rat to make no more efforts to return so I put it back into the nest.

Another young rat was then put into compartment 1. Its first movements were as often away from its mother as toward her. Finally in its wanderings it came within reach of its mother's mouth and was drawn inside. When tried again in compartment 1, the same thing happened. I next put the rat into compartment 2, but it made no effort to get back, although its mother was making frantic endeavors to reach it. After 15 min. of useless waiting I thought best to return it. By this time the mother had become almost frantic, and further tests were discontinued.

From the above tests on the rats of ten days of age no definite conclusion, as regards the presence of the associative processes, can be drawn. The first rat experimented upon seemed at first to make definite efforts to get back to its mother; the second rat made no attempts whatever to return. If the memory processes are present at all in rats of ten days of age, they must be so

slightly developed as to be of little use in bettering the condition of the young rat. Up to ten or twelve days of age, life to the rat is a matter of pure instinct. Rats at that age show very few signs of purposeful movement, unless they are disturbed. If the mother moves the position of the nest, she must carry each baby rat with her. If, however, they feel the mother over them, they will fall on their backs and sides and begin to suck. If in leaving the nest the mother scatters her young, they manage to huddle up near one another.[1] An interesting thing in the above experiments comes out in regard to the mother's care for her young; whenever a little fellow grew uncomfortable during a test it would utter a shrill squeak, which would invariably bring the mother's head to the opening.

February 24 (twelve days of age). — In order to give the mother time to get over her fright thoroughly, experiments were omitted for one day. By the end of the twelfth day the rats had grown considerably larger and movement had become much better co-ordinated.[2]

A young rat was started in compartment 3. It went at once through *b* and wandered around compartment 2 for a time. Finally it went through *d*, then straight on through *f*. Its mother was in the back of the box, but the little fellow walked on through the straw and did not stop until it reached her. Its mother appeared not to have missed it at all. Time: 8 min.

Second trial: This time the rat returned in 1 min. It chose exactly the same pathway as before. This was a definite and businesslike procedure.

Third trial: This time it went straight home through *a-c-e* and scrambled through the straw as before. (In making its way through the straw it was often pricked, and each time a straw jagged it it would make a plaintive squeak.)

Fourth trial: I next closed *a-d-e*, leaving *b-c-f* open. The

[1] *Cf.* SMALL, *American Journal of Psychology*, Vol. XI, No. 2.

[2] Before beginning experiments on the above date, I marked one rat with India ink, so that I could be sure I was testing the same one always.

rat was started in compartment 3 as before, but nearer *b* this time. It went straight through *b* and stopped at the middle of the first cross-piece. Finally it found the opening *c* and entered, then went straight to *e*. Finding this closed, it went straight to *f* without "feeling" its way, and entered. Time: 4 min.

Fifth trial (openings as in the above test): This time the rat went through *b*, then through *c*, and over to *e*, as in the last test. In this trial it lost no time at *e*, but went over to *f* and entered. Time: 2 min.

As a further test I closed *e* with a strip of pasteboard and put sawdust lightly over *f*. The rat did nothing with this test, however. It even avoided the sawdust. I suppose the olfactory and tactile sensations set up by the sawdust were unpleasant. The mother had become uneasy by this time, so I carried the experiments no farther.[1]

The definiteness and rapidity with which this young rat returned to the mother left but little doubt that the associative processes were present. The time for each successive return was cut down, and useless movements were discontinued. In other words, there was the ability present in this rat to profit by experience.[2]

February 25 (thirteen days of age).—Experiments like those of the two preceding days were again taken up. A young rat was put into compartment 3 for the first trial. It waited for 8 or 10 min. before making any effort to return. Finally I poked it with a pencil and shoved it along through the entrances. The rat's mother happened to be near the opening when it entered the box and it began at once to suck. This was a fortunate circum-

[1] There has been a decided advance in the development of these young rats within the last two days. At ten days of age they spent nearly all their time in the nest, not even leaving it when the mother left. Today (at twelve days of age) they followed the mother everywhere. The floor of the box was covered with straw, which made walking rather difficult.

[2] In finding the entrances today, this young rat did not crawl along the sides of the compartments, as did the rats at ten days of age, but went as directly to them as it is possible for a rat to go without having sight to guide it.

stance, since it left a good taste in the baby's mouth. It was tried in this way three or four more times, and each time it went back just as rapidly as its legs would carry it. It was then tried with a number of complications; if it had been choosing a straight pathway, such as *a-c-e*, for its return certain of the entrances were closed, thus necessitating the selection of an indirect route. But nothing in this line seemed to give it any insurmountable difficulty. If an entrance was closed that the rat had been accustomed to go through, it would nearly always go to this entrance before seeking another. It seemed to me that this very clearly demonstrated the presence of memory.

The entrance *e* was next closed with cardboard, while sawdust was lightly piled over *f*. The entrance *e* was the one the rat had last gone through. When put down in compartment 1, it went at once to *e* and butted at the cardboard. The rat next went to *f*, but the sawdust seemed to be unpleasant, so it returned to *e*. Here it butted and clawed with all its strength. This was a definite attempt, which showed there was a strong impulse to go through that particular entrance.[1]

February 26 (fourteen days of age).—I began work today by taking out two of the rats and letting them return to the mother several times. After they had associated one entrance (*e*) leading directly to the mother, I closed this with cardboard and put sawdust over the other entrance (*f*) also leading directly to the mother. Both began work at once upon the entrance closed with the cardboard. They bit and tore at this for a long time, but would not go near the sawdust. I then sprinkled sawdust everywhere. This made the "feel" and odor of the sawdust a constant factor. The two rats were tried again, and this time the little

[1] The eyes of the rats were not yet open, but their ears were. Any high-pitched noises, such as the dropping of a small brass weight into the scale pan, caused the rats to react strongly. SMALL (*American Journal of Psychology*, Vol. XI, No. 1, p. 85) was certainly wrong when he said that the ears and eyes of the rat open simultaneously. I have investigated this with several groups, and I found that some rats first become sensitive to sound on or about the twelfth day of their life. At first they are sensitive only to noises of very high pitch; medium- or low-pitched noises, no matter how great in volume, have no effect upon them.

fellows made straight for the entrance closed with sawdust and began scratching as definitely and purposively as a full-grown rat would have done. They were tried in this way several times, and the time required for success in each trial in the series was less after each repetition.

By this time the associative processes are well established— well enough established to be of some practical value to the rat in his efforts to keep near a "base of supplies."[1]

February 27 (fifteen days of age). — Experiments were begun on this date by placing all seven of the young rats in compartment 3 (all entrances were left open). It was 5 min. before all of them returned to the mother. When tried again, the last to arrive reached the mother in 1 min. The third time all returned in 0.41 min. On the last trip they scrambled over one another in their eagerness to get back.[2]

I next completely closed the two entrances *e* and *f* with sawdust. All the other entrances were left open. All seven rats ran at once into compartment 1, but finding sawdust over the two entrances leading to the mother, they were puzzled for a short time. Finally two scratched into the box, one at each entrance. Time: 0.50 min. The other five followed immediately. The two successful ones were in all probability the rats I had used in yesterday's experiment.

These two rats were then marked and were made the subjects for the rest of the experiments for that afternoon. The next test was as follows: *e*, *f*, *c*, and *d* were closed with sawdust; *a* and *b* were left open. The rats were put into compartment 3. Both rats went to *c* and *d*, but, finding sawdust there, seemed too lazy

[1] Within the last two days a change had come over the mother. When the rats were ten days of age, the mother became frantic if she saw one of the young rats beyond her grasp. When her young were fourteen days of age, she was not at all worried when I took one of them out for an experiment. Indeed, for two days past she had not received the young rats in her mouth as they entered the box, but allowed them to scramble through the straw to her as best they could. Mills noticed this same change in the dog (*Animal Intelligence*, p. 128).

[2] Their eyes had opened, but vision seemed to be of very little use, except perhaps in assisting the rats in the rapidity of their orientation.

to work. Accidentally one of them, in its wanderings, partly disclosed the entrance *c*. Both began scratching then and went into compartment 1, and there they rested for a long time. The rats were old enough not to be always hungry, and since the room was very warm (72 Fah.), they were perfectly comfortable. The easiest way to get quick reactions from a rat is to starve it, but as this was impossible in the present case, I decided to try the effect of cold. I then sprinkled a little snow over the rats, and both of them woke up and scratched through *e* in a hurry.

Before repeating this test with them I cooled the rats thoroughly by placing them in a dish that was resting on snow. When given the above task again they did not tarry long on the way, but scratched back in less than 1 min.

February 28 (sixteen days of age).—The same kind of preliminary test was made at the beginning of today's work that was made yesterday. All seven of the rats were put into compartment 3 and allowed to return. Time: 0.25 min. Sawdust was then put around *e* and *f*. Two rats were successful in 2 min. These two rats were then marked, and the rest of the tests for that day were made with them.

All the entrances were then covered with sawdust. Time of the return of these two rats: 3 min.; again in 2 min. Both times these rats went back by way of *a-c-e*. *c* was then closed with cardboard, and the rest of the entrances with sawdust as before. The rats scratched through *a* and went immediately to *c*, as I expected. After butting at *c* for a time, they went over to *d* and scratched through; then they went diagonally over to *e* and entered.

March 1 (seventeen days of age).—All the rats were sleeping. I woke them up by putting them into compartment 3 and letting them run back to the nest, which they did immediately. I then began pouring sawdust around *c* and *d*. Hearing the noise, the rats came out and investigated. This was the first day they had done this. This faculty for investigating, so characteristic of rats, developed wonderfully fast in this group from day to day.

I closed *c* and *d*, *e* and *f*, with sawdust, and started all seven of the rats in compartment 3 (this being the usual procedure for finding the brightest rats). Time for first return: 4 min.; second return: 0.55 min. I then chose two of the brightest rats and continued the tests with them.

I allowed these two rats to establish an invariable order of return—*a-c-e;* I then closed *a-d-e* with pasteboard and the other entrances with sawdust. Both of them began work by tearing and butting at the pasteboard on *a*. Finally they gave this up, and went over to *b* and scratched through. They then went diagonally over to *c*. Scratching through this, they went directly to *e*. At first nothing would induce them to leave *e*. There they stayed biting and tearing at the tacks that held the pasteboard. One could hear them biting at the tacks fifteen feet away. Fearing they would injure their mouths, I partly disclosed *f*. Finally one of the rats left *e* and finished scratching away the sawdust around *f*. Time: 16 min. I then let them go back over this same pathway without closing the entrances with sawdust. They went to *e* as before, but when they found it closed they went over to *f* almost at once. I then closed the entrances with sawdust, thus giving them their previous task over again. Time: 4 min.

The above tests concluded the work, with this group, on the first period in the development of the young rat. We have tried to show, as completely as possible, by our experiments the general nature of the psychical development that the rat has attained at this early age. In our search for the first appearance of the associative processes we began, when the rats were ten days of age, with tests as simple as we could make them, and gradually as the psychical and physical elements developed we tried to give the rats more and more complicated tasks which would serve to bring out the increasing complexity of this development.

It now remains for us to study the second period in the development of the young rat.[1]

[1] See p. 60.

B. TESTS TO DETERMINE APPROXIMATELY THE EARLIEST AGE AT WHICH THE RAT HAS REACHED A DEVELOPMENT JUST SUFFICIENT TO ENABLE IT TO SOLVE THE STANDARD PROBLEMS.

It might be well to state a little more fully just what is meant by the "standard problems." The first part of this paper discusses at length the various problems suited to the associative ability of the rat. It will be remembered from the description given there that in determining the kind and complexity of the problems which a rat is capable of solving we began with a simple problem—one the various parts of which could be associated by the rat after a single success; and ended with a problem which required thirty to forty successful trials in order to establish the association.

The following is a list of the "standard problems" which have been previously presented:

No. 1—The Problem of Box I (p. 13).
No. 2—The Problem of the complication of Box I (p. 17).
No. 3—The Problem of the labyrinth (p. 22).
No. 4—The Problem of the labyrinth having its entrances closed with sawdust (p. 29).
No 5—The Problem of Box II (p. 33).
No. 6—The Problem of Box III (p. 36).
No. 7—The Problem of Box IV (p. 37).

The method used for determining the earliest ages at which these problems can be solved was as follows: The first four of the problems were given serially to the group of seven rats now under consideration. After these four problems had been successfully solved the group was divided into three subgroups, X, Y, and Z. Each of these subgroups was then put to work upon one of the three remaining problems. Group X had for its task the problem of Box II, Group Y that of Box III, and Group Z that of Box IV.[1]

[1]The reason for thus subdividing the group I shall now endeavor to explain. Before beginning work upon the present group of rats, I experimented upon another group, with the same general purpose in view—that of finding the earliest ages at which these problems can be solved. I began this work by giving the rats, serially, all seven of the problems. I found, as a consequence of the time

The group of rats now under consideration was not subdivided until after the first four problems had been solved, because these problems were very simple and served to accustom all the young rats alike, not only to a change of food—from the mother's milk to bread soaked in milk—but also to overcome difficulties in obtaining their food.

This method of subdividing the group on the more difficult associations, and giving only one problem to each subdivision, seemed to be the best solution of the difficulty I met with in experimenting upon the first group.

March 2 (eighteen days of age).—On this date I gave Box I for investigation to all seven of the young rats. Milk-soaked bread (the stimulus used in all the following tests) was placed inside the box. The rats investigated the outside of the box very thoroughly, and two of them entered, but did not touch the food. After a little while all except two of the rats crawled under the box and went to sleep. These two continued in their examination of the box and its surroundings.

I next put sawdust lightly around the box—enough, however, to conceal the entrances. The rats showed a lively interest in the sawdust, but did not offer to scratch under the box. Finally all curled up on the sawdust and went to sleep. I left them there, and upon returning I found that two rats had scratched under the box and gone to sleep. I do not believe the box had been entered. However, this might at least have indicated that some memory of their previous stay there had been retained. I then put the rats back with their mother.

March 3 (nineteen days of age).—I tried them again today with Box I, but they showed not the slightest signs of hunger, and so made no efforts to get at the food.

necessarily involved, that before the last problem in the series had been solved the rats were forty-nine days of age. I felt sure that the most difficult problem in the series could have been solved long before that age, if the rats had been allowed to work upon that one problem and no other. In other words, with the method I first used, before the last problem in the series could be given to the rat he had already passed the age at which he could first have solved it.

March 4 (twenty days of age).—Early in the morning of this date I weaned the rats. When tried with the regular problem of Box I (3 o'clock in the afternoon), the rats were still not hungry enough to show much interest in their task. Finally after 18 min. one rat scratched under the box and entered. The others soon followed it. On the second trial one rat scratched under and entered before I could time it. This rat was then removed. (In order permanently to distinguish this rat, in subsequent experiments, from the others in the group I marked it by cutting gashes in its fur.) The remaining six rats were then tried again. They scratched underneath the box and lay down there for a nap. Since a rat with its stomach full is a failure as a *Versuchsthier*, I made no further tests that day.

It will be seen that the above tests on March 2, 3, and 4 (when the rats were eighteen, nineteen, and twenty days of age, respectively) gave no satisfactory data for determining the progressive increase in the associative ability of the rats. The difficulty lay in the fact that the stimulus was changed from the mother's milk to bread soaked in milk, and since the rats were still unweaned, the bread offered them no inducement to enter Box I.

When the rats were eighteen days of age I tried to construct a labyrinth of pasteboard tubes and attach it to the box where the mother and young were kept. As I was constructing the labyrinth, the young rats came out and began running up and down in the tubes. I knew then that it would be useless to continue further experiments with the mother as the stimulus. The rats had reached an age at which they could go longer without food than formerly, and consequently were in no hurry to return to the mother. Their own fur, too, had thickened, and they no longer required the warmth of the mother's body.

It is clear now that at the above age, if the rats are experimented with *unweaned*, no satisfactory results will follow. This difficulty I avoided in a subsequent group by weaning the rats at sixteen days of age.[1]

[1] P. 80.

March 5 (twenty-one days of age).—I began experiments today with Box I by trying again the one rat that was successful yesterday. When put into the cage containing Box I it seemed very anxious to get at the food. Time of entrance: 2.5 min. Second trial: 0.66 min.

Two other rats from the group were next given this problem again. They were hungry by this time and began to dig at once. They happened to dig on the wrong side of the box, however, and grew discouraged. I opened up the entrances part of the way; then the rats came up and entered. When tried again they entered in 1 min.

Two others from the group were then tried again. Time of first entrance: 24 min.; time of second entrance: 0.50 min.

The last two from the group were then tried. They lost so much time biting at the wires and scratching in useless places that I partly opened up an entrance. When tried again they entered before I could time them.

March 6 (twenty-two days of age).—The marked rat was first given Box I. The association of the problem had been perfectly retained. Time of entrance: 0.75 min.

The rest of the rats had retained the association also. Their time of entrance was longer than that of the above rats, but their work was sufficiently good to demonstrate their ability to overcome any difficulty like that offered by Box I.

From these experiments, extending over something like five days, we saw that the problem of Box I was first solved by one rat when it was twenty days of age. We saw that this rat definitely retained the association of the problem, as evidenced by the rapidity with which the rat solved the problem in all subsequent tests. We found also that all of the remaining rats had not definitely formed the association until they were twenty-two days of age.

From these results it must not be inferred that this is the earliest age at which this problem can be solved. All that can be inferred is that, under the same conditions, this problem can be solved by a rat at least twenty days of age.

On the same day these rats were given the complication of Box I. When I first gave them the problem I was afraid that they would meet with great difficulty in removing such a quantity of sawdust. But I was never more pleasantly surprised in my life—every rat began scratching as if its life depended upon the amount of sawdust it individually removed. In less than 1 min. they had entered the fence, and in 3 min. more every rat had entered the food-box. On the second trial one rat entered the food-box before I could time it. This was by far the cleanest-cut work that these rats had ever done, or that any rat had ever done on that particular problem.

The rapidity with which this problem was solved proves, it seems to me, that long before the age of twenty-two days was reached the memory processes had reached a development sufficient to enable the rats to solve any of the problems conditioned chiefly upon activity. Indeed, some of the tests conducted upon these rats when they were fourteen, fifteen, and sixteen days of age involved fully as much associative ability as is involved in a test like that of Box I.

March 7 (twenty-three days of age).—The problem of the labyrinth.

Before beginning experiments with the labyrinth, I tried them again with the complication of Box I. The rats perfectly remembered its complication, entering in less than 1 min.

The labyrinth (all entrances open) was then given to the rats. All seven began going into the blinds at once. After 1 min.'s work one rat went to the food; at the end of 5 min. all seven of the rats had entered. They were then tried again with the labyrinth. This time they were put into the cage on the side opposite to the true entrance—in the previous test they were put in on the side nearest it. One rat ran around to the true entrance and reached the food in 0.83 min.; the other rats, however, made many useless movements before finding the true entrance. When tried a third time one rat dashed directly to the true entrance and

reached the food in 0.25 min. Another one followed almost at once. The rest entered a few seconds later.

The entrances of the labyrinth were then closed with sawdust. The rats were not very hungry after having gone to the food so many times in the previous tests, but I wanted them at least to make a start upon this problem. When I had banked up the sawdust 3 in. high around the fence I felt badly discouraged—to scratch away that much sawdust looked like a big job for such little rats. However, one rat soon opened up the south blind and came out on the east side. All seven of the rats then began to run through the blinds. But they gave up before the true entrance had been disclosed. Although the problem was not solved, one interesting thing came out of the test, which shows the persistence of a useless habit. In the tests with the labyrinth when the entrances were not closed with sawdust several of the rats formed the habit of coming out of the east blind and twisting themselves directly around into the true entrance. This they tried to do when the true entrance was still closed with sawdust. It was very amusing to watch them try to do this and fail, then chase around to the south blind, come out at the east side again, and try the same thing over.

March 8 (twenty-four days of age).—In order to aid the rats in forming the association of the true entrance to the labyrinth, I began work today by only half closing it with sawdust. Two rats were then tried. They opened up the blinds first, then made a dash for the true entrance. I then gave them the regular problem. Both rats made a dash for the true entrance and reached the food in 0.66 min.

The other five rats were then tried. After one or two successes the association was perfectly formed.

March 9 (twenty-five days of age).—This group of rats was today divided into three subgroups.[1]

The utmost care was taken with these subgroups of rats. Milk-soaked bread was their sole diet. This was fed to the rats

[1] See p. 69.

in their respective problem boxes just at the close of experiments with them. Each rat ate as much of the food as it desired, and was then returned to the nest. In this way no food was ever left around their living-cages; consequently when the time of day came to begin experiments with them, they were always hungry. The experiments were conducted at the same hour on successive days.[1]

SUBGROUP X (AT WORK UPON BOX II).

This subgroup of rats (two rats) began work upon Box II by tearing at the wires around the door of the box. They were very active—springing easily from the floor of the cage to the top of the box. After 22 min. had passed, one rat opened the door by repeated pushes upon the latch. When the door opened, the rat was not frightened, but seemed puzzled at first, for it stood there pushing up and down on the latch after it had fallen from its socket. On the second trial the rat began work again by pushing at the latch and tearing at the wire spring with its teeth and claws. Time: 0.75 min. The third trial the rat again lost time by making useless efforts to tear away the spring from the door. Time: 2 min. Again in 0.50 min. I tried the rat again, but its hunger had been satisfied and it made no farther efforts to open the door. The other rat in the subgroup was in the main merely a spectator. Sometimes, however, it appeared to make efforts to assist its companion.

SUBGROUP Y (AT WORK UPON BOX III).

The string, opening the latch inside Box III, had been rubbed with cheese before the rats were put to work. This group (three rats) was so hungry that I thought best to open the door of the box and let each rat eat a moment before trying to experiment

[1]The work on a previous group of rats the results of which are not recorded (see note, p. 69), taught me the necessity of care in regard to the amount and kind of food to be given a rat if it is desired to conduct experiments upon him. For instance, if a full meal of cheese is given to a rat on one day, it will be two days later before he will be hungry enough to work. If bread, however, is given to the rat on one day, he will be hungry on the following day, provided that only the amount is given him which he will eat up at once.

with them. When they were tried with the problem they ran at once to the door of the box and tried to pry underneath it. They worked vigorously, but never once offered to pull the string, although I kept it always moistened with milk and cheese. I allowed them to work away until they gave up, and then I opened the door and let them eat their fill.

SUBGROUP Z (AT WORK UPON BOX IV).

The two rats in this division were exceedingly hungry. I put a drop of milk on the inclined plane, and almost immediately, in their efforts to get the milk, the rats caused the plane to fall. The rats were so very light that it was necessary for them to go completely out to the end of the inclined plane in order to throw it. This necessarily made the association of the problem more difficult for these young rats than it was for the heavier rats.

When tried again, both rats ran at once to the door of the box, as would be expected. It is unnecessary to go farther into the details, however. At the end of the experiments they had not begun to form the association.

March 10 (twenty-six days of age).

SUBGROUP X.

The two rats in this division at first showed no recollection of their previous experience with Box II. Many useless movements were made in running over the box and around the cage. Finally memory seemed to return and one rat neatly opened the box. Time: 3 min. On the second trial the box was opened in 0.25 min. This time the work was beautifully done—both rats struck at the latch. On the next trial the latch was opened before I could record the time. The rats were tried several times more, and each time they opened the latch immediately. The association seemed perfect.

SUBGROUP Y.

These rats were at first too wildly eager for the food to notice the string, but after two minutes of useless work one rat reached up and in nibbling at the cheese pulled the string, and thus opened

the door. On the next trial, however, the rats showed not the slightest signs of remembering how the door had been previously opened. They were given many more trials at the problem, and on each trial the string was accidentally pulled. Toward the end of the day's work, however, the rats seemed to have gone a little way toward forming the association.

SUBGROUP Z.

One rat sprung the inclined plane in its first rapid chase around the cage. On the next trial both rats ran at once to the door, but one of the rats—deliberately, it appeared to me—then walked out on the plane until it fell. On the next trial this rat again walked out on the plane and threw it. This rat was then tried alone several more times, and each time it purposively threw the plane. The association was not definite, however, even when experiments were stopped for that day.

March 11 (twenty-seven days of age).

SUBGROUP X.

The two rats in this division were tried again, just to see if they remembered their task. On every trial the box was immediately opened. This completed the work with this division.

SUBGROUP Y.

After three trials on this date the three rats in this division began to pull the string as rapidly as I could close the door. I then put on a new string, one free from the odor of milk or cheese. Changing the string did not cause them to enter the box less rapidly; so I concluded that the association was perfect.

SUBGROUP Z.

After four more trials on this date the rat which had been partly successful yesterday sprung the inclined plane as rapidly as I could readjust the apparatus.[1]

[1] This rat also associated the several steps in going to the food in an invariable order.

March 12 (twenty-eight days of age).—The respective tasks of the three subgroups were perfectly accomplished. This completed the work on this litter of rats.

EXPERIMENTS SUPPLEMENTARY TO THE PRECEDING.

From the above tests it appeared that there was a break in the development of the associative processes when the rats were seventeen, eighteen, and nineteen days of age. In order to show that this apparent break was due to lack of stimulation, I determined to supplement the above series with experiments on another group, weaning the rats at sixteen days of age instead of waiting until they were twenty days of age.

Since in the above tests there was some doubt as regards the presence of memory in the rat at ten days of age, I thought it worth while to make a few additional tests with rats at ten days of age.

March 7 (ten days of age).—This litter of rats appeared to be better developed at ten days of age than was the previous group. I saw one rat actually leave the nest.

Several hours before beginning the experiments I put the mother and young into the box of the apparatus described on p. 61.

I began experiments by taking out two rats and putting them into compartment 3. One rat returned in 5 min.; on a second trial it returned in 2 min. Both times the mother received it in her mouth and drew it gently through the entrance. On a third trial the rat went back as rapidly as it could crawl. The second rat made no efforts to get back. The mother soon became worried, so I continued the tests no further.

If definiteness in return, and the cutting down of the time for successive returns, be taken as an index of the presence of associative ability, I should say that such ability was manifested by one of these rats.

March 8 (eleven days of age).—No experiments were conducted upon the above date, because the mother had been too much disturbed by the previous experiments.

March 9 (twelve days of age).—One rat in the litter was permanently marked, and all the rest of the tests in which the mother was used as a stimulus were conducted with this rat alone. It was, as far as I could judge, the brightest in the group which contained four rats.

Experiments were begun on the above date by putting this marked rat into compartment 3. At first it made no effort to return. Finally hunger or cold began to affect it, and it returned through *a-c-e*. Time: 12 min. Second trial: the rat returned by way of *a-c-e* as before. Time: 1 min. Again: this time it went back through *b-d-f*. Time: 0.16 min. On the next trial it again went home through *a-c-e*. Time: 0.16 min.

I then closed *c* with pasteboard and started the rat near *a*, so that naturally it would continue its way through *c-e*. It went straight to *c*, as I expected it would, and for 4 min. the rat bit and tore at the pasteboard. Finally it went over to *d*, then continued through *f*. On the next trial, with the entrances as in the last test, the rat went to *c* as before, but it did not tarry so long there as previously, but went almost at once through *d* and on to *f*. In trying to drag the young rat through *f* on this last trip, the mother turned its body crosswise of the entrance and hurt the little fellow. After that I attempted no further experiments on that day.

March 10 (thirteen days of age).—The young rat was all right again after a night's rest, so I began experiments with it again today. I allowed this rat to establish an invariable order of return through *a-c-e; c* was then closed. I desired to find out how many times it would continue going to *c* before crossing diagonally over to *d*. On the fourth return the rat did not go to *c*, but went from *a* to *d* and on through *f*.

Experiments on March 11 and 12 were omitted, because I had already obtained on those days good results from the previous group of rats.[1]

[1] In the afternoon of March 12 (when the rats were only fifteen days old) the eyes of the rats in this group opened.

March 13 (sixteen days of age).—The rats were weaned on this date.

March 14 (seventeen days of age).—The rats were first given Box I for examination. They were still not hungry. The rats were very fat when I weaned them, and I suppose they were living on their surplus fat. However, curiosity caused them to poke their heads up through the hole in the floor of the box.

Sawdust was then piled up lightly around the box. It should be noted that these rats had neither seen nor smelled sawdust before. All the rats walked around the box once or twice, but they did not offer to scratch in. I let them "nose" about for ten minutes; then I helped them in by scratching away a part of the sawdust from the entrance. I tried them again. Two rats pushed their way underneath the box and entered, but did not touch the food. I then stopped work with them putting them back into the nest without having fed them.

March 15 (eighteen days of age).—They were exceedingly hungry today and very active, solving the problem of Box I in 2 min.; again in 0.15 min. The rapidity with which this test was solved showed that the association had been formed by the previous day's experience.

The complication of Box I was given the rats at once. Almost immediately the rats began scratching in the sawdust around the fence containing Box I, and in 1 min. the problem had been solved.

On the next trial two of the rats entered without making any useless movements. Time: 0.16 min.

March 16 (nineteen days of age).

LABYRINTH TESTS.

Before giving the rats the problem of the labyrinth I tried them with the complication of Box I. I heaped up the sawdust higher than ever before. One rat entered in 0.50 min. without making a single useless movement.

Only two rats were used in the tests with the labyrinth. The

labyrinth was first given them with all the entrances open. After 15 min. one rat found the true entrance—after repeatedly trying all of the blinds. The other rat did not appear to know how to begin. Both rats were at first a little afraid to enter the blinds. They would thrust their heads into the entrances and then draw back. In this respect their behavior was much like that of the adult rats. On the second trial one rat reached the food in 0.50 min. On the third trial this rat reached the food in 0.25 min. without making a useless movement.

March 17 (twenty days of age).—Before giving these two rats the problem of the labyrinth with its entrances closed by sawdust I tried them again with the labyrinth as used in yesterday's experiments (all entrances open). Their memory of the place of the true entrance was perfect.

Sawdust was then piled up to the usual height around the openings. For the first minute the rats seemed lost; one rat ran around to the true opening, but did not offer to scratch in. A few seconds later it came back and opened up the east blind, went in a little way, then turned around in the blind, and came back to the true entrance and opened it up like a flash. Time: 2 min. This problem had never before this been solved in so short a time.

On the second trial this rat again went to the true entrance and opened it up, this time without disturbing a single blind. On the third trial the same thing happened. The work of this rat on this test was phenomenal.

No further experiments were made upon this group of rats. My purpose in experimenting with them was to show that the memory processes are continuous in these animals during the seventeenth, eighteenth, and nineteenth days of life.

Let us summarize briefly now the results obtained from this investigation of the lower stages of memory.

At ten days of age we found, with the first group of rats, that the evidence for the presence of memory was not at all conclusive.

With the second group of rats the evidence was more satisfactory, but still not entirely conclusive.[1]

At twelve days of age there was no doubt that memory was present in the rats of both groups. The return to the mother was definite and businesslike. Not only did their general behavior give one the impression that memory was present, but the time for each successive return was cut down, and useless movements were discontinued.

At thirteen days of age we found that memory was developed sufficiently to enable the rats to return to the mother over a pathway as complicated as it could be made with the apparatus used (that is, by closing some of the entrances and leaving others open. It should be remembered that we failed to get the rats at twelve days of age to return to the mother when the entrances were closed with sawdust).

At fourteen, fifteen, and sixteen days of age we found that the rats could solve any problem that could be devised with the apparatus. Entrances were closed with sawdust and cardboard in a number of ways, and, no matter how complicated the pathway, the rats could always return to the mother. We found on those days that the rats remembered the pathways they had previously traversed successfully. For a time useless movements over these pathways were made (showing the presence of associations), but these after a time were discontinued and the new pathway adopted (showing still better the presence of intelligence).

It will be remembered that in the attempt to show the increasing complexity of psychical development poor results were obtained with the first group of rats from the sixteenth to the twentieth day. The reason for obtaining these poor results I have already explained as being due to a lack of adequate stimulation. With the second group of rats better results were obtained.

[1] Rats under ten days of age which I experimented upon in the same way failed to show any signs of memory. I could not get them even to return to the mother.

The rats in this group were weaned on the sixteenth day. The results obtained from this latter group show that on the seventeenth day the psychical and physical elements were developed sufficiently to enable the rats to solve the first of the "standard problems."

On the eighteenth day the associations of the parts of Problem I were definitely made and Problem II was solved for the first time.

On the nineteenth day Problem III (labyrinth, with all entrances open) was solved.

On the twentieth day Problem IV (labyrinth, entrances closed with sawdust) was quickly solved.

Returning now to the first group of rats, we found that they finished Problem IV at twenty-four days of age (four days later than the second group). The first group was weaned four days later than the second group. Undoubtedly this makes the solving of the subsequent problems (V, VI, and VII) by the first group three or four days later than the rats could have solved them, provided this group had been weaned at sixteen days instead of twenty. The group was then divided into three subgroups, and each of these subgroups was given one of the three remaining problems. Group X completed the associations required for the solution of Problem V (Box III, latch on the outside) at twenty-six days of age—after working two days. Group Y completed the associations required for the solution of Problem VI (Box III, latch inside, string releasing latch hung outside) at twenty-seven days of age—after working three days. Group Z also completed the associations required for the solution of Problem VI (Box IV, inclined plane, falling trap) at twenty-seven days of age, after working three days.

From these experiments I think we may safely conclude that the rat reaches psychical maturity at from twenty-three to twenty-seven days of age.

Let us now bring together briefly the main points that have been determined by the present study.

A. I. Comparison between the activities of young and adult rats.

1. No form of problem which the adult rat is capable of solving presents insurmountable difficulties to the rat of twenty-three days of age.

2. *a)* The time of first success in solving problems conditioned chiefly upon physical activity is shorter for young rats than for adults.

b) For the second solution of such a problem, adult rats do not require a longer time than young rats.

c) Problems not so conditioned upon physical activity are solved, even the first time, more quickly by adult than by young rats.

3. *a)* Young rats make many more useless movements than adults.

b) After once associating the various parts of a problem, adult rats make only the movements necessary to attain the desired end, while young rats — owing to their superabundant physical activity and lack of muscular control — continue to make useless movements long after adult rats have discarded them entirely.

c) There is a gradation in the number of useless movements made by rats at different ages. At thirty-five days of age, when physical activity appears to have reached its highest stage, the percentage of useless movements is largest. As the rats grow older this superabundant activity disappears, and in its place comes direction of activity.

II. The use of the senses.

1. Smell.

a) In their search for food rats use mainly the sense of smell.

b) Smell (perhaps in conjunction with the tactile sense) appears to be employed as the most important means of making exact co-ordinations to objects close at hand.

c) Young rats do not track one another through entrances, etc. by the sense of smell. After sexual maturity is reached the element of tracking may play an important role in the life of the rat.

2. Sight.

a) Apparently vision serves in the largest part to furnish crude, general orientation.

b) Other things being equal, rats show a decided preference for well-lighted rather than dark places.

3. Hearing.

Sound seems to direct the adult rat but little in obtaining food; it does appear to aid the very young rat in returning to its mother (that is, before the eyes are opened).[1] The sense of hearing appears to have its chief value for the emotions of danger and satisfaction of hunger.

As far as our experiments have been conducted, they show that smell is the sense most depended upon by the rat. This does not mean that rats are incapable of forming complicated associations through the senses of hearing, sight, and temperature.

B. The early stages of memory.

1. Until the rat has reached the age of twelve days, life to it is simply a matter of pure instinct. Certain movements are made, but these movements are dependent upon the ready-made adjustments of

[1]The method by which a rat finds its way over a zigzag pathway (see experiments on young rats when the mother was used as a stimulus) when not guided by smell or sound, and when still blind, is, at the moment, unexplained. It looks like a case of motor memory.

neural and motor elements with which the rat begins life; intelligence plays little or no part.

2. At twelve days of age memory is present in a simple form.

3. From the twelfth to the twenty-third day there is a gradual but rapid increase in the complexity of the memory processes until at the latter age psychical maturity is reached. Development after this age is analogous to the development that takes place in a child of ten years as he gradually becomes more and more mature.

PART II.

The Development of Medullation in the Central Nervous System of the White Rat.

I. Introduction.
   1. Purpose of the Work.
   2. Technique.
      a) Selection of Material.
      b) Treatment of Material.

II. The Development of Medullation in the Medulla Spinalis.
   1. In the Cervical Region.
   2. In the Thoracic Region.
   3. In the Lumbar Region.
   4. The Change in Area of the Cord from Twenty-four Days to Maturity.

III. The Development of Medullation in the Cerebellum.

IV. The Development of Medullation in the Cerebrum. Change in Area of the Brain from Twenty-four Days to Maturity.

V. General Summary.

I. INTRODUCTION.

I. PURPOSE OF THE WORK.

The white rat is born without medullated nerve fibers.[1] The study of the development of the medullation in the nervous system of this animal should be of interest, and comparatively easy to follow because of the abundance of the material, and the certainty and exactness with which the sequence of medullation can be traced.

The first specific object in undertaking such an investigation was primarily to furnish the basis for a correlation between the growth of the nervous system of the white rat and the activities of that animal. In Part I the writer made a study of the psychical development of the white rat, and found that at twenty-four days of age it is to all intents and purposes psychically mature, the criterion of maturity being the rat's ability, at that age, to solve any problems that an adult rat can solve. In consideration of this fact, the point of greatest interest, under this heading, will be the difference between the development of the medullation in the central nervous system of the rat at twenty-four days of age and at maturity. The correlation, as such, between the psychical development of the white rat and the development of the nervous system of that animal does not at present concern us, but will be discussed in Part III.

The second point in the general purpose of the investigation was to obtain data for a comparison between the sequence of medullation in the central nervous system of the white rat and the human fœtus. Owing to their wide separation in the mammalian scale, the nervous systems of the rat and man can be compared only in their larger features.

The literature bearing upon the subject of the development of medullation will be discussed in connection with this second point.

[1] H. H. Donaldson, *American Text Book of Physiology*, Vol. II, p. 181.

II. TECHNIQUE.

a) Selection of material.—The white rats used in this investigation were raised by the writer and every care was taken to surround them with the best conditions for growth. The following table shows that the body weight of the rats used in this work for the most part is far above that of rats not having had especial care.

TABLE SHOWING THE AGE, WEIGHT, AND SEX OF RATS WHOSE NERVOUS SYSTEMS WERE EXAMINED.

Age.	Weight. (gr.)	Sex.	Age.	Weight. (gr.)	Sex.
2 hours	4.017		13 days	21.2	male
1 day	5.58		14 days	24.2	male
3 days	6.94		15 days	25.9	male
4 days	6.82		16 days	26.44	male
5 days	7.71		17 days	30.76	male
6 days	13.60		18 days	33.9	male
7 days	15.38		19 days	35.76	male
8 days	12.50		20 days	34.1	male
9 days	11.12		24 days	16.5	male
10 days	16.09		35 days	53.5	male
11 days	17.82		42 days	76.31	male
12 days	23.10	male	Adult	286	male

It will be noted in the above table that the weight of the rats does not steadily increase with age. But fortunately, within wide limits, this makes little or no difference for the present investigation, since the development of the nervous system depends upon age rather than upon the body weight. To illustrate this point compare Fig. 11 with Fig. 6. The two rats weigh almost the same; the rat in Fig. 11 was twenty-four days of age; the rat in Fig. 6, eleven days of age. The ages of the rats as tabulated above is exact almost to the hour.[1]

b) Treatment of material.—The brain and spinal cord of the rats were dissected out and put in Müller's fluid for two and one-half months (without heat). Sections were then made and prepared in accordance with the Pal-Weigert method.

[1] Two other series of rats were put up and treated in this same way, but since they were used only for comparison, they need no further mention.

The sections from the spinal cord were made at the levels of the sixth cervical, eighth thoracic, and third lumbar nerves. The cerebellum was split longitudinally down the vermis, and the sections were made parallel to the face of this cut. The cerebrum was divided in the middle line, and transverse sections were then made (either the right or left hemisphere) at the level of the infundibulum. After the sections were mounted, twenty-seven of them best illustrating the points involved were drawn,[1] and from these drawings the half-tones in the present paper were made. The magnification of these half-tones of the spinal cord is 20 diameters (the same magnification being used for all ages and for all levels of the spinal cord). The magnification of the cerebellum and cerebrum is 10 diameters, and likewise the same for all ages.

The sections from which the illustrations appearing in the present paper were made, were chosen as follows:

Cervical	Thoracic	Lumbar	Cerebellum	Cerebrum
3 days (Fig. 1)	3 days (Fig. 2)	3 days (Fig. 3)		
6 days (Fig. 4)				
9 days (Fig. 5)			9 days (Fig. 20)	
11 days (Fig. 6)				
13 days (Fig. 7)				14 days (Fig. 24)
16 days (Fig. 8)				
18 days (Fig. 9)				
20 days (Fig. 10)				
24 days (Fig. 11)	24 days (Fig. 12)	24 days (Fig. 13)	24 days (Fig. 21)	24 days (Fig. 25)
35 days (Fig. 14)	35 days (Fig. 15)	35 days (Fig. 16)	35 days (Fig. 22)	35 days (Fig. 26)
Adult (Fig. 17)	Adult (Fig. 18)	Adult (Fig. 19)	Adult (Fig. 23)	Adult (Fig. 27)

The sections are marked according to both level and age. The letters appearing on the illustrations are explained in the description of the section on which they appear.[2]

II. THE DEVELOPMENT OF THE MEDULLA SPINALIS.

I. THE CERVICAL REGION.

As was said in the introduction, the nervous system of the rat contains no medullated fibers at birth. Since beginning the present work, sections of the nervous system of this animal at birth and at twenty-four hours of age have been carried through

[1] The drawings were made by Mr. A. P. Streedain, to whom I am greatly indebted for his careful and excellent work.

[2] The references to figures in Part II are to those on Plates I, II, and III, at end of book.

according to the Weigert method (Dr. Donaldson's statement was made upon the basis of osmic acid preparations). The sciatic nerve of the new-born rat was also prepared as the above. In no part of the nervous system at these ages could medullated nerve fibers be found.

Sections of the cervical region of the cord of a rat two days of age show a few scattered, medullated nerve fibers both in the ventral funiculus and in the funiculus lateralis. The dorsal funiculus is entirely unmedullated. The peripheral nerve roots are almost entirely lacking in medullated fibers, the dorsal roots being completely so.

Sections at this level from the cord of rats three days of age (see Fig. 1) show several additional fibers in the regions just described. At this age medullated fibers begin to appear in the fasciculus cuneatus (F. C., Fig. 1). In this fasciculus the medullated fibers are found first in a narrow stripe extending from the dorsal surface of the cord down to the area occupied by the pyramidal tract (P. T., Fig. 1).[1]

The extra medullary portion of the peripheral roots at this age show many medullated fibers. The medullation process is, however, far better advanced in the ventral roots.

Sections at this level from the spinal cord of rats four and five days of age show many individual variations. The sections from the rat four days of age contain almost no medullated fibers, while the sections from the rat five days of age are just comparable to those from the rat three days of age, as above described. The dorsal roots of the rat five days of age are almost entirely lacking in medullated fibers, while the extra medullary portion of the ventral roots contains many darkly stained fibers.

Sections of this region from the rat six days of age show again a steady increase in the number of medullated fibers and in the area of the cross-section. It is at this age that medullated

[1] The pyramidal tract occupies, in the rat, the ventral tip of the fasciculus cuneatus. This area is oval in shape, extending over both sides of the median septum.

fibers first appear in the fasciculus gracilis. They are confined to no particular place in the sections of the fasciculus, but sparsely scattered throughout its entire extent. A few scattered fibers are found in the area occupied by the pyramidal tract, but I am inclined to think that these fibers belong to the fasciculus cuneatus. At this age, for the first time, medullated fibers can be seen decussating in the commissura anterior alba.

An examination of the sections from the cord of the rats aged seven, eight, and nine days (for the last see Fig. 5) shows a remarkable increase in the area of cross-section of the cord. The fibers in the fasciculus gracilis begin to take a definite position, being thickest nearest the septum which divides the fasciculus gracilis from the fasciculus cuneatus. The more ventral portions of this stripe are the better medullated. The pyramidal area is still little advanced. At this age a few medullated fibers can be seen in the gray matter of the ventral horn.

Sections at this level from the eleven-day rat (Fig. 6) show the ventral and lateral funiculi to be uniformly filled with fibers. At this age, however, the fibers are separated from one another by some little distance. By this time the fasciculus cuneatus is about as well medullated as the ventral funiculus. The fasciculus gracilis shows medullated fibers everywhere, but the stripe next the cuneatus fasciculus, and especially the ventral portion of this stripe is still more darkly stained. Numbers of fibers can now be traced from the gray matter of the ventral horns out into the ventral roots. For the first time large fibers from the dorsal roots can be seen swinging from the root entry zone into the gray matter of the dorsal horns. A large increase in the number of fibers can be noted in the pyramidal tract.

At this age (a very few of these fibers could be seen on the previous day) isolated bundles of cross-sectioned fibers, extending from the lateral limiting layer almost to the tip of the ventral part of the fasciculus cuneatus can be seen (H, Fig. 6). These bundles of fibers are found just ventral to the substantia gelatinosa. A few fibers can now be seen in the commissura posterior alba. In this section, just ventro-lateral to the sub-

stantia gelatinosa, a light area appears. Prior to this age this area seemed to be really a part of the substantia gelatinosa. It is possible that we have here a lateral pyramidal tract, since from now on we see this area behaving exactly as does the area allotted to the pyramidal tract in the dorsal column.

An examination of sections at this level from the twelfth to the fifteenth day shows changes mainly in the increased number of fibers in the gray matter. Larger masses of fibers can be seen leaving the gray matter to run in the ventral and lateral funiculi of the cord. The only areas not containing some medullated fibers on the fourteenth day are those around the central canal and in the substantia gelatinosa of the dorsal columns.

At fifteen and sixteen days we have one thing of interest besides the gradual increase in the number of medullated fibers; namely, the fasciculus gracilis is very prettily divided—almost as clearly as if a septum of connective tissue had grown in (M, Fig. 8). The memberment begins at the center of the dorsal surface of the fasciculus and runs diagonally to the median septum. By this time the dorsal surface of both divisions of the fasciculus are equally well medullated, but the ventral portions of both are still more darkly stained. The area in the white substance ventral to the substantia gelatinosa has by this time become much clearer, being only lightly stained, while the fibers in that part of the fasciculus lateralis adjoining it have become much darker.

During the seventeenth, eighteenth, and nineteenth days (Fig. 9 shows the eighteenth day) there has been little change in the area of the cross-section of the cord. The increase in the number of the medullated fibers, too, has been relatively small. The light area (X, Fig. 8) now contains an increased number of medullated fibers.

The fasciculus gracilis from sixteen days on is clearly divided into three smaller fasciculi. The two most lateral, and especially the ventral, portions of these are still better medullated.

At twenty days of age the cervical region again shows an

increased area of cross-section, but the number of medullated fibers within the gray matter of the cord has not advanced much.

Sections at this level from the rat twenty-four days of age show one distinct advance over the last section just described: the fasciculus gracilis now has the medullated fibers evenly distributed over its entire extent. These fibers are not as closely packed nor as darkly stained as they are at maturity.

The ventral funiculus up to this time has increased only slightly in area since the fourteenth day, but the funiculus lateralis has greatly increased its area.

Not much has been said concerning the increase in the number of medullated fibers in the pyramidal tract. Even at this age only a few fibers are present. The development of this tract is very slow.

Up to this age all the fibers in the sections have taken the stain lightly, compared with the dark stain that appears in the section from the adult rats.

The next rat was killed at thirty-five days of age. Sections from the cervical region of this rat show a greatly enlarged area of cross-section. The stain has become much darker, being comparable with that found in the adult specimens. The fasciculus gracilis has become as well medullated as the fasciculus cuneatus. The advance in all directions—increase in area, increase in the number of fibers to a given area, complexity of the fiber network in the gray matter, etc.—has been very great during the preceding eleven days of growth.

Just when new medullated fibers cease to appear in the spinal cord of the rat is difficult to determine. Sections from the cord of a rat forty-two days of age show an advance in every direction over the stage of development found in the rat at twenty-four days. Sections from the cord of the rat at seventy days of age likewise show an advance in development over that found in the rat of forty-two days.

Examining now the sections of the cord of the adult rat (Fig. 17), we find that the fibers are very closely packed together and very darkly stained. The area of the gray matter of the cord is

relatively small in comparison with that of the rat twenty-four days of age. The space between the dorsal and ventral funiculi has been so reduced in area that the funiculi almost meet.

Strange to say, even at the adult stage the pyramidal tract is still only lightly stained. I have made several preparations of the cord of adult rats, and this area is always more lightly stained than the surrounding ones. Sometimes in the same set of sections this area will stain more darkly in one than in another. This leads me to believe that the sheaths of the pyramidal fibers have a slightly different chemical composition from those of the other fibers.

The area (X, Fig 8) is still visible in the adult stage and behaves toward the stain just as the pyramidal area. It seems to me that we can conclude from the uniformity of the behavior of these two areas to the stain that we have the same kind of fibers in both areas; if this is true, we have here a lateral pyramidal tract.

II. THE THORACIC REGION.

At two days of age the thoracic region of the cord is almost unmedullated. Here and there a dark-blue speck can be seen, which may, by courtesy, be called a medullated fiber.

At three days (Fig. 2) a few medullated fibers can be seen in the ventral and lateral funiculi. These fibers are few in number and widely scattered. The process of medullation in the thoracic cord is much behind that of the cervical cord at the same age except, as we shall see later, in the fasciculus gracilis.

In the dorsal funiculus the fasciculus cuneatus shows a number of scattered fibers. These fibers are about equally distributed throughout the extent of the fasciculus. In this section about twelve medullated fibers can be counted in the fasciculus gracilis. The extra-medullary portion of the ventral roots is beautifully stained, while that of the dorsal roots is entirely unstained. (Compare D. R., dorsal roots, and V. R., ventral roots, in Fig. 2.)

Sections at this level from the rats aged four and five days show the same variation that has already been noted in the discus-

sion of the cervical cord, except that in the thoracic region the variation is more marked, only a few fibers being present in the ventral funiculus, while none are present in the lateral and dorsal funiculus.

At six days we have again the definite increase in the number of medullated fibers. All three funiculi—ventral, dorsal, and lateral—have added new fibers. The position of the pyramidal area now comes out quite clearly, but does not yet contain a single medullated fiber. The cervical cord at this age, it will be remembered, showed a few medullated fibers in the area occupied by this tract. The cervical region at this age also showed some medullated fibers within the gray matter of the cord, but no such fibers are present at the level of the eighth thoracic nerve.

The thoracic region at six days contains in the fasciculus gracilis many medullated fibers—markedly more than was found in the cervical region of the same rat. These fibers are found in the ventral part of the fasciculus.

Sections of the cord at this level from rats aged seven, eight, nine, and ten days show the gradual thickening up of all the fiber tracts. At this age we find one advance in this level over that found in the cervical region—the fasciculus gracilis throughout its entire extent contains more medullated fibers than was found in this fasciculus at the level of the sixth cervical nerve. At eight days this fasciculus begins to show some signs of membermentment. As was the case in the cervical region, the fasciculus gracilis is more darkly stained in its ventral portions. At the latter age, faint fibers can be seen in the commissura anterior alba. On the tenth day a few fibers are present in the pyramidal tract.

The backwardness of the medullation process in the dorsal root fibers is remarkable; even at ten days the ventral roots are much more darkly stained than the dorsal.

At eleven days, medullated fibers begin to appear in the gray matter of the cord. The number of medullated fibers in the pyramidal tract has increased. The light area lying ventral to the substantia gelatinosa appears at this age. Fibers, too, can now

for the first time be seen swinging from the root entry zone into the gray matter of the dorsal horns. At this age medullated fibers can be traced from the gray matter out into the ventral and lateral funiculi.

Sections from this region of the cord at twelve, thirteen, and fourteen days show nothing of interest except the gradual development. At fourteen days the fibers mentioned in the description of the cervical cords as extending from the lateral limiting layer to the fasciculus cuneatus (H, Fig. 6) first becomes apparent in the thoracic region. Here the bundles are small, and continue small, not comparing in point of size with those found in the cervical region. In this section fibers swinging in from the root entry zone can be traced down to their ending near fibers which make up the commissura anterior alba. This gives us a pathway for a direct reflex.

At fifteen, sixteen, and seventeen days we find an increased number of medullated fibers in the pyramidal tract. The number of medullated fibers within the gray matter has also increased.

Sections at this level from rats aged eighteen, nineteen, and twenty days show little change. At eighteen days a large number of medullated fibers can be seen decussating in the commissura posterior alba.

At twenty-four days (Fig. 12) we find an advance in several directions. The fasciculus gracilis is now as darkly stained as the fasciculus cuneatus. The lateral and ventral funiculi have increased in size, and the fibers are more closely packed together. The isolated bundles of cross-sectioned fibers (H, Fig. 6) have increased in size and in number. The dorsal root fibers and the fibers in the commissura anterior alba come together in a beautiful way just dorso-lateral to the central canal.

At thirty-five days the fibers have taken on a yet darker stain. All the fasciculi have greatly increased in size during the preceding eleven days of growth. The whole dorsal funiculus is now darkly stained. The dorsal roots and their collaterals can be traced far down into the ventral portion of the cord. At this age fine medullated fibers can be seen in the substantia gelatinosa.

The advance in the development of the thoracic region has been like that found in the cervical region. The ventral and lateral funiculi have increased greatly in area, while the area of the gray matter has enlarged relatively little. The lateral funiculus has developed out of all proportion to the rest of the funiculi in the cord.

Two areas in the adult thoracic cord remain only lightly stained—the area occupied by the pyramidal tract and the area ventral to the substantia gelatinosa.

III. THE LUMBAR REGION.

No medullated fibers are found in the lumbar region until the third day.

At three days (Fig. 3) a few medullated fibers can be seen upon the ventral border of the ventral funiculus. The position of the fasciculus cuneatus can be seen, but no medullated fibers are present. The extra medullary portion of the ventral roots contains many darkly stained fibers. If we compare Fig. 3 with Fig. 1, we see that the process of medullation in this level at three days is not nearly so well advanced as the cervical region at the same age.

Sections of the lumbar region from the cord of rats four and five days of age are still no better developed, only a few medullated fibers being present in the ventral roots and in the ventral funiculus.

At six days we have our first definite increase in the development of medullation. A section of the lumbar region at six days is just comparable, as regards the amount of medullation, to a section of the cervical region at three days.

At eight days the fasciculus cuneatus is about as darkly stained as the ventral funiculus. At this age a few fibers can be seen in the fasciculus gracilis. Even the extra medullary portion of the dorsal roots is almost entirely lacking in medullated fibers.

The sections taken from the cord of rats aged eight to eleven days vary greatly, sections from the seven- and nine-day rats containing medullated fibers only in the ventral funiculus.

At eleven days we have another definite advance in the increase of the area of cross-section of the cord and in the process of medullation. Several medullated fibers can, at this age, be seen in the pyramidal tract. The light area ventral to the substantia gelatinosa is visible in this section.

The fasciculus gracilis is very small. At this age it is divided into two wedge-shaped divisions, both being slightly medullated. At twelve days we find the lateral funiculus encroaching upon the substantia gelatinosa. The fibers in this funiculus have become more numerous and are stained more darkly; consequently the light area mentioned above, by contrast, appears more plainly. Scattered fibers are present at this age in this light area.

At fourteen, fifteen, and sixteen days we find little change, but on the whole a slight advance over the thirteen-day stage of development can be noted. At fourteen days the dorsal roots are as well medullated as the ventral roots, both intra and extra medullary divisions being medullated. At the latter age we get our first sight of the isolated cross-sectioned bundles of fibers extending across the cervix of the dorsal horn.

At seventeen days the area of the cross-section of the cord has enlarged. All the fasciculi are much more darkly stained, and their fibers are more closely packed together. The fasciculus gracilis is still more lightly stained than the fasciculus cuneatus.

The increase in medullation during the eighteenth, nineteenth, and twentieth days has been rapid. The white matter, taken as a whole, has greatly increased. At twenty days the fasciculus gracilis is as darkly stained in all its parts as the fasciculus cuneatus. This event takes place rather earlier in the lumbar region than in either the thoracic or the cervical regions.

The sections at this level from the cord of the rat at twenty-four days show little change in the stage of development found in the lumbar region of the rat at twenty days of age.

At thirty-five days (Fig. 16) there has been a great increase in the number of fibers within the gray matter of the cord. The illustration shows that all the fasciculi, with the exception of the gracilis, have increased greatly in size. To the end this fasciculus remains quite small.

From thirty-five days to maturity the lumbar region increases greatly in area of cross-section. Illustration 19 shows that during this period all the fasciculi have greatly increased their number of medullated fibers. Comparing illustrations 19 and 13, we find that at twenty-four days the lumbar region is still very immature.

Here, as in the other regions of the cord, the pyramidal area and the area ventral to the substantia gelatinosa are still more faintly stained than the adjacent areas.

IV. THE CHANGE IN AREA OF THE CORD FROM TWENTY-FOUR DAYS TO MATURITY.

Miss Allen has kindly made for the writer some planimetric measurements of the increase in the area of the cross-section of the cord from twenty-four days to maturity. The result of these measurements is shown in the following table:

CERVICAL REGION.

	White	Gray	Total
24 days	2.380 sq. mm.	2.572 sq. mm.	4.952 sq. mm.
Adult	5.808 sq. mm.	3.081 sq. mm.	8.889 sq. mm.

THORACIC REGION.

	White	Gray	Total
24 days	1.368 sq. mm.	1.175 sq. mm.	2.543 sq. mm.
Adult	3.949 sq. mm.	1.113 sq. mm.	5.062 sq. mm.

LUMBAR REGION.

	White	Gray	Total
24 days	1.035 sq. mm.	2.527 sq. mm.	3.562 sq. mm.
Adult	3.610 sq. mm.	3.167 sq. mm.	6.777 sq. mm.

PERCENTAGE OF INCREASE.

a) CERVICAL REGION.

	White	Gray	Total
24 days	——	——	——
Adult	144.0	19.7	79.5

b) THORACIC REGION.

	White	Gray	Total
24 days	——	——	——
Adult	188.0	— 5.2	99.0

c) LUMBAR REGION.

	White	Gray	Total
24 days	——	——	——
Adult	248.7	25.3	90.2

In addition to the above changes in the area of the cross-section of the cord, we have the following data upon the increase in weight and length of the spinal cord of the rat from twenty-four days to maturity:

Average weight of the cord of the rat at 24 days ..... .208 gr.
Average weight of the cord of the rat at maturity..... .605 gr.
Average length of the cord of the rat at 24 days.....49.64 mm.
Average length of the cord of the rat at maturity..... 100 mm.
Per cent. of increase in the weight of the cord from 24 days to maturity..198.5
Per cent. of increase in the length of the cord from 24 days to maturity..100.1

(The above table is based upon the records kept in this laboratory.)

A consideration of these figures shows that the total area of the cross-section of the cord has greatly increased from twenty-four days to maturity.[1] Furthermore, the relative increase of the white over the gray matter has been enormous.[2] If now this greatly increased area in the white matter is to be completely filled at maturity with medullated fibers, three things may happen: *(a)* the fibers already present at twenty-four days may increase in size proportionately to the increase in the area of the cross-section of the white matter of the cord; or *(b)* new medullated fibers may be added; or *(c)* there may be both an increase

[1]For further reference in regard to this point consult the paper by DR. DONALDSON AND MR. DAVIS, "A Description of Charts Showing the Areas of the Cross-Section of the Human Spinal Cord at the Level of Each Spinal Nerve," *Journal of Comparative Neurology*, Vol. XIII, No. 1 (March, 1903).

[2]Indeed, one record in the above table, the thoracic, shows an actual diminution in the area of the gray substance from twenty-four days to maturity. This is by no means the only instance of this. Other planimetric measurements in this same series show that the gray matter in the lumbar region at thirty-three, thirty-five, and seventy days, in the thoracic region at thirty-five and seventy days, in the cervical region at thirty-three, thirty-five, and seventy days, is actually greater than at maturity. These measurements, however, were all made upon one series of sections (the series described in the present paper) and this decrease in the gray matter of the cord may need other measurements to confirm it.

in the size of the fibers present at the earlier age and an addition of new fibers. According to some unpublished work done by Miss Allen in this laboratory, it appears that in the white matter, after the field is completely filled with medullated fibers—for example, at thirty-five days—the subsequent increase in the size of the fibers there found is less rapid than the increase in the total area of the white substance; from which it follows that new fibers must be added.

It will be of interest in this connection to mention some investigations that have been made in regard to the increase in the number of medullated fibers in the peripheral nervous system of the white rat.

Hatai[1] has recently counted the number of medullated fibers in the dorsal and ventral roots of the white rat at different ages. In the 24.5-gram rat (approximately twenty-four days of age) the number of medullated fibers in the dorsal sixth cervical root was found to be 2,567, while the number in a rat weighing 167 grams (adult) for the same nerve was 4,227. A slightly greater ratio of increase was found to hold in the above rats for the fourth thoracic and the second lumbar. Practically the same thing was found to be true for the ventral roots, except that the ratio of increase was not so great. In a rat weighing 25.4 grams (approximately twenty-five days of age) Hatai found in the sixth cervical 1,207 medullated fibers, while in a rat weighing 164.9 grams (adult) he found 1,474 medullated fibers in the sixth cervical, and here likewise a slightly greater increase holds for the fourth thoracic and the second lumbar. In the ventral roots we have then an increase in the number of medullated fibers from twenty-four days to maturity of over one-third. We see from this investigation that a rat at twenty-four days of age has approximately one-half of the final number of its dorsal root fibers and two-thirds the final number of its ventral roots medullated.

[1] SHINKISHI HATAI, "Number and Size of the Spinal Ganglion Cells and Dorsal Root Fibers in the White Rat at Different Ages," *Journal of Comparative Neurology*, Vol. XII, No. 2. (Dr. Hatai has not yet published his observations upon the ventral roots, but with his consent I use the above observations.)

III. THE DEVELOPMENT OF THE CEREBELLUM.

As has already been stated, sections from the cerebellum were cut in the median plane, parallel to the vermis. Such a section shows the stem (M, Fig. 23) of the white substance in the center of the middle lobe of the cerebellum ramifying into the laminæ medullares (A, B, C, D, E, F, G, Fig. 23).

The present description of the process of medullation in the cerebellum will deal with *(a)* the time at which medullation begins, and *(b)* the progress of medullation in the laminæ medullares (A, B, etc.).

In this section medullation begins in the stem of the central white substance at eight days (M, Fig. 23, for the position of the stem).

At nine days (Fig. 20) the number of medullated fibers in this place has not noticeably increased. These fibers are all cross-sectioned. One day later a few longitudinal fibers can be seen.

At eleven days longitudinal fibers are present in laminæ B, C, and D. These laminæ are noticeably more advanced than any of the others. During this last day of growth the number of medullated fibers has increased remarkably. Two days later (the thirteenth day) all the laminæ except A contain medullated fibers. The laminæ B, C, and D are now far in advance of the others. The side branches of these contain a few medullated fibers. One day later the lamina A contains a few medullated fibers. During the last twenty-four hours the number of medullated fibers has increased greatly in all of the laminæ.

During the fifteenth, sixteenth, and seventeenth days the growth of the cerebellum is rapid. All the laminæ begin to take the stain more darkly and the section presents a characteristic cerebellar appearance. During this period of growth the fibers in the laminæ most advanced in the process of medullation—for example, B, C, and D—reach the granular layer. A few fibers can be seen to pass out into this layer.

Development from the seventeenth to the twentieth day is marked by the increase in the number of fibers that leave the main trunk of the laminæ and turn to end in the granular layer. This takes place all along the pathway of the laminæ.

At twenty-four days the laminæ have increased greatly in area. The fibers are far more closely packed together. At this age the fibers in the laminæ pass through the granular layer, extending to the inner edge of the molecular layer. However, the fibers that spread out, fan-like, through the granular layer are still few in number (Fig. 21).

Indeed, development from twenty-four days on can best be seen in the ever-increasing number of fibers that spread out into the granular layer.

At thirty-five (Fig. 22) and forty-three days the increase in the medullated fibers extending into the granular layer has been enormous. At this age the laminæ and their branches are well filled out with darkly stained fibers. Comparing Fig. 21 with Fig. 22, we find that comparatively few of the medullated fibers in the branches of the laminæ at twenty-four days reach the granular layer.

The adult cerebellum is shown in Fig. 23, and the illustration shows, far better than a description can tell, the wonderful increase in the number of medullated fibers that has taken place even since the thirty-fifth day.

IV. THE DEVELOPMENT OF THE CEREBRUM.

As was stated in the introduction, transverse sections from one hemisphere at the level of the infundibulum were chosen for the study of the development of medullation in the cerebrum. Sections in this plane show the corpus callosum (C. C., Fig. 24) the external capsule (C. E., Fig. 24), the corpus striatum (St. B., Fig., 24), the anterior portion of the thalamus (T., Fig. 27), the commissura anterior (A. C., Fig. 24), and the stria olfactoria lateralis (OL. T., Fig 24).

In this section medullation begins in the external capsule of the rat at eleven days. These fibers, at this age, do not appear along the entire extent of the capsule, but only in a definite and limited portion of it (C. E., Fig. 24). The fibers in this region, at this age, are few in number and are very lightly stained.

At thirteen days a few more medullated fibers are present in this region. The fibers in this section are more deeply stained

than in the one just described. At this age the position of the rest of the external capsule and that of the corpus callosum can be made out. A yellow striated appearance, caused by the unmedullated fibers, marks the whole extent of what will later be the medullated external capsule and corpus callosum.

At fourteen days (Fig. 24) we find a large increase in the number of medullated fibers in the external capsule. At this age we find for the first time medullated fibers in the corpus callosum. The position of the corpus callosum at this age comes out quite clearly, and numerous unmedullated fibers can be seen there as yellow lines. The olfactory pathway contains numerous faintly stained fibers. The development of this tract for the previous twenty-four hours has been very rapid, since at thirteen days no medullated fibers were present. The corpus striatum at fourteen days contains several small bundles of faintly stained fibers (radiations from the internal capsule to the cortex R. C. I., Fig. 24). The position of the commissura anterior can be seen at this age, but is entirely lacking in medullated fibers. Medullated fibers are present in the area marked OL. R., in Fig. 24 (probably radiations from the olfactory tract).

Sections of the cerebrum at this level from rats fifteen days of age show again an increased number of medullated fibers in the capsula externa. The medullated fibræ longitudinales dorsales have increased somewhat in number. The corpus callosum is still almost entirely unmedullated. The commissura anterior is entirely so. At this age (a few of these fibers could be seen at fourteen days) medullated fibers can be seen raying out from the capsula externa to the cortex. These fibers can at fifteen days be traced out into the cortex only for a short distance; they extend probably not farther than one-eighth of the total distance to the surface of the cortex.

At seventeen days we find everywhere a wonderful increase in the number of medullated fibers. Such fibers occupy now the whole field of the external capsule, and the fibers radiating from this region into the cortex are much more numerous and extend for a longer distance toward the surface of the cortex. The

whole field occupied by the corpus callosum is now faintly stained. The commissura anterior for the first time contains medullated fibers. These fibers are few in number and are poorly stained. Numerous faintly stained fibers are now present in the thalamus.

At eighteen days the advance in medullation is most apparent in the increased number of fibers in the olfactory tract. Indeed in this section the corpus callosum and the commissura anterior are behind the seventeen-day rat in development. In this eighteen-day section almost no medullated fibers are present in these two pathways.

The chief thing of interest in the advancement found in the cerebrum of the rat at nineteen days of age is the great increase in the size and number of the isolated bundles of medullated fibers found in the corpus striatum.

At twenty-four days (Fig. 25) the advance in the section is noted mainly in the still further increase in size and number of the isolated bundles of medullated fibers found in the corpus striatum. Fig. 25 shows very well how these bundles of fibers cross the corpus callosum and enter the cortex. This comes out quite plainly in the section because of the almost unmedullated condition of the corpus callosum. The commissura anterior is likewise only faintly stained. At this age we find an increased number of fibers in the thalamus. The drawing gives a good idea of the number of fibers raying out toward the surface of the cortex as well as the level to which they extend.

At thirty-five days (Fig. 26) the development in the amount of medullation has been marked. The corpus callosum is now darkly stained. The fibers in the capsula externa are closely packed together. The commissura anterior, however, is not as darkly stained as in the adult cerebrum. A glance at the illustration shows that the number of fibers projecting into the cortex has greatly increased and that they come nearer to the surface.

Fig. 27 gives but a poor idea of the beauty of the adult cortex of the rat. The fibers in the cortex are thickly packed and come almost to the surface. The increase in the number of medullated fibers in the cortex since the thirty-fifth day has been almost unbelievable.

The fibers in the corpus callosum, commissura anterior, and in the external capsule at maturity take the stain equally well. The medullated fibers in the thalamus and in the area OL. R. (Fig. 24 for position) have greatly increased in number. The drawing shows this well.

As will be seen from the illustration, a new system of fibers can be seen in the adult cerebrum—a zonal layer (Z. L., Fig. 27). In the cerebrum of the rat used in the present work this layer of medullated fibers does not extend far around the side of the cerebrum, being clearest just along the mesial surface of the cortex. In a later preparation this band of fibers can easily be traced almost around to the stria olfactoria lateralis. In this later preparation the fibers raying out into the cortex can be traced completely out to the zonal layer.

This strand of zonal fibers in frontal sections cut anteriorly to the corpus callosum extends far down the mesial surface of the cerebrum.

CHANGE IN AREA OF THE BRAIN OF THE RAT FROM TWENTY-FOUR DAYS TO MATURITY.

Weight of the brain of the rat at 24 days..... 1.356 gr.
Weight of the brain of the rat at maturity..... 1.880 gr.[1]
Area of section of the cerebellum made in a sagittal plane in the mid-line at 24 days ..... 16.19 sq. mm.
Area of section of the cerebellum made in a sagittal plane in the mid-line at maturity .....22.11 sq. mm.
Area of cross-section of the cerebrum at 24 days.....39.37 sq. mm.
Area of cross-section of the cerebrum at maturity.....48.41 sq. mm.
Increase in weight of brain from 24 days to maturity..... 38.6 per cent.
Increase in the area of the above section of the cerebellum from 24 days to maturity ..... 36.5 per cent.
Increase in the area of the cross-section of the cerebrum from 24 days to maturity ..... 21.6 per cent.

VI. GENERAL SUMMARY.

Under this heading we will bring together in the form of a table the statements found to be true in this series of sections concerning the order and progress of medullation in the central

[1]This weight for the brain at maturity is a little below the maximum that may be attained.

ORDER OF MEDULLATION IN THE SPINAL CORD OF THE RAT.

Divisions	Cervical Region—Medullation Begins at	Thoracic Region—Medullation Begins at	Lumbar Region—Medullation Begins at	Remarks on the Rapidity of the Medullation Process
1. Funiculus ventralis	2 days	3 days	3 days	Rapid
2. Funiculus lateralis	2	3	3-6	Rapid
3. Ventral roots:				
a) Extra medullary portion	2	3	3	Very rapid
b) Intra medullary portion	8	8	8	Rapid
4. Funiculus dorsalis:				
a) Fasciculus cuneatus	3	3	4-6	Rapid
b) Fasciculus gracilis	4-6	3	6	Slow, the field not becoming evenly filled and uniformly stained until about the 24th day
c) Pyramidal tract	6	10	11	Very slow, not staining uniformly even at maturity
5. Dorsal roots:				
a) Extra medullary portion	3	3	4-6	Slow
b) Intra medullary portion	8	8	8	Slow

ORDER OF MEDULLATION IN THE CEREBELLUM OF THE RAT.

Divisions	Medullation Begins at	Remarks
In stem of central white substance	8 days	Development in the cerebellum is more rapid than in the cerebrum
In laminæ B, C, D (Fig. 23)	11	At 15, 16, and 17 days fibers reach (and a few ray out into) the granular layer. From this age on the number of these fibers spreading out into the granular layer becomes an ever-increasing one
In laminæ E, F, G (Fig. 23)	13	
In laminæ A (Fig. 23)	14	

ORDER OF MEDULLATION IN THE CEREBRUM OF THE RAT.

Divisions	Medullation Begins at	Remarks
Capsula externa	11 days (in that portion designated by C. E. in Fig. 24)	Rapid
Fibræ longitudinales dorsales	13 days	Slow
Stria olfactoria lateralis	14	Very rapid
The corpus striatum	14	Rapid, numerous cross-sectioned bundles of fibers can be seen at 24 days in this division
The corpus callosum	14	Very slow until after the 24th day. At the 35th day all the medullated fibers in the field are blackly stained
Radiations into the cortex	14	Development extremely slow. At 24 days of age the medullated fibers raying out into the cortex are comparatively very few. At maturity this field is the most beautiful and the most complex of the whole central nervous system of the rat
Commissura anterior	17	Very slow until after the 24th day. At 35 days the fibers are as darkly stained as those in the corpus callosum
Thalamus	17	Slow
Zonal layer	? (But certainly not before the 42d day)	

(In the above table some of the dates are fixed at 4-6 days. This is due to the fact that sections from the cord of the rats aged 4 and 5 days showed no advance over the rat 3 days of age in the number of medullated fibers—not until the 6th day do we again get a certain and sure advancement.)

nervous system of the white rat. Following upon this appears the order of medullation in the human central nervous system.

Turning to the literature upon the sequence in the medullation process we find that it is confined almost wholly to investigations upon the central nervous system of man.

Von Bechterew[1] gives us a concise statement upon the order of medullation in the human medulla spinalis.

1. That portion of the ground bundle which adjoins the anterior horn.
2. (*a*) Anterior zone of Burdach.
   (*b*) Middle zone of Goll's fasciculus.
3. The rest of the ground bundle.
4. Direct cerebellar tract.
5. (*a*) The middle zone of fasciculus cuneatus.
   (*b*) The posterior zone of fasciculus cuneatus.
6. The medial bundle in the lateral funiculus.
7. Fasciculus antero-lateralis.
8. Remainder of Goll's bundle and the marginal zone.
9. Pyramidal and olivary tracts.

From Flechsig we get the following remarks upon the time involved from the first appearance of medullation in the fasciculi to their complete "Markumhüllung."[2]

The anterior ground bundle: The anlage is visible in fœtuses *4 weeks of age*. In fœtuses 25 cm. in length medullation is as complete in this tract as in the pyramidal in fœtuses 49 cm. in length. Time of medullation process about 4 months.

What is true for the above fasciculus holds true for the external part of the posterior fasciculus (*äusseren Hintersträngen*) and for the great part of anterior portion of the lateral mixed zone (*vorderen gemischten Seitensträngen*).

Fasciculus gracilis:[3] The anlage appears at the *beginning* of the *third month*. Medullation is complete at the *end* of the *sixth month* to the beginning of the seventh. Duration of the process of medullation about 4 months.

The direct cerebellar tract: The anlage appears at the *beginning* of the *third month*. Complete medullation appears at the end of the *seventh month*. Time of medullation process 4 months.

Pyramidal tract: Medullation begins toward the *end* of the *fifth month* of fœtal life. The process of medullation is completed at the end of the *ninth month* (on fœtuses 48–49 cm. in length). Time involved in process of medullation 4-4½ months.

ORDER OF MEDULLATION IN THE HUMAN CEREBRUM. (FLECHSIG.)

At birth medullated fibers are found in the external and internal capsules and in the white masses of the lenticular nucleus.

Toward the last of the *eighth month* of *fœtal life* the centripetal fibers begin to invest themselves with myelin. Fibers connecting the telencephalon with the posterior funiculi of the medulla spinalis are the first of such fibers to become medullated; then those from the olfactory bulb; then successively those from the gray terminal masses, from the optic, and from the acoustic regions.

By the end of the *first month after birth* the descending fibers (fibers which have their cells of origin in the gray masses constituting Flechsig's "sensory spheres"—visual, auditory, olfactory, etc., spheres) have become completely medullated.

At the beginning of the *second month after birth* medullated fibers begin to connect these "sensory spheres" with one another and with what Flechsig calls "centers of association." Medullation here goes on until late in life.

[1] *Leitungsbahnen im Gehirn und Rückenmark*, p. 102.

[2] FLECHSIG, *Leitungsbahnen im Gehirn und Rückenmark*, p. 193.

[3] For details in the changes in the medullation of this fasciculus consult Dr. Barker's excellent summary of TREPINSKI's paper, "Die embryonalen Fasen-Systeme in den Hintersträngen und ihre Degeneration bei der Tabes dorsalis," BARKER, *Nervous System*, p. 430.

From Theodore Kaes[1] we have the following statements concerning the zonal layer in the cortex of man: After the projection fibers have reached their normal limit of extension, and just before the outer association layer is completely medullated, two sets of fibers appear; one is found surrounding the outer limit of the projection fibers (the Gennare or Baillarger layer), the other is the zonal layer at the ectal border of the cortex. The stage of development just described is characteristic of the cortex of the child one and one-fourth years of age.

[1]From a paper entitled "A Brief Summary of the Researches of Theodore Kaes on the Medullation of the Intra-Cortical Fibers of Man at Different Ages," by HELEN BRADFORD THOMPSON, *Journal Comparative Neurology*, Vol. X, No. 3, October, 1900, p. 363.

PART III.

A Correlation between the Psychical Development of the White Rat and the Development of Medullation in its Central Nervous System.

I. Introduction.

II. The Increasing Activity of the Rat from Birth to Ten Days of Age Correlated with the Increase in Medullation During That Period.

III. The Increasing Activity of the Rat from Ten to Twenty-four Days of Age Correlated with the Increase in Medullation During That Period.

IV. The Bearing of This Study upon the Correlations Made by Flechsig.

I. INTRODUCTION.

In the introduction to Part I of this series of investigations it was said that an attempt would be made to answer the following questions: Is it possible to find out whether or not medullated nerve fibers in the cortex of the rat are a *conditio sine qua non* of the rat's forming and retaining definite associations? Is there any demonstrable connection between the increasing complexity of the psychical life of the rat as manifested in the ability of the rat to form increasingly complex associations, and the number of the medullated fibers together with the extension of the medullated fibers toward the surface of the cortex?

Using the results that have been obtained from the study of the activities of the white rat, and those from the study of the development of medullation in the central nervous system of that animal, the attempt will be made to show the lack of connection between medullation and function in *(a)* acts involving predominatingly the use of the spinal cord, and in *(b)* those involving the use of the cortex.

II. ACTIVITIES OF THE WHITE RAT FROM BIRTH TO TEN DAYS OF AGE CORRELATED WITH THE INCREASE IN MEDULLATION DURING THAT PERIOD.

Small, in his *Notes on the Psychical Development of the Young White Rat,* tells us that at birth the rat is able to make certain definite co-ordinated movements, chief among which are the following: sucking, which is done while the animal is lying on its back; wriggling over to a side position when placed upon its back; movements of the tail; vocal efforts—three being possible: a clucking sound, a "wirelike" squeak, and a short sharp chirp.

Again, the rat is sensitive at birth. According to Small, all the rats in a group of five noticed the odor of violet perfume. The proof of their ability to use the sense of smell was found in

the expressive movements which the animals made whenever they were subjected to this stimulus. (Other stimuli were used, for example, HCl, but the present writer lays most weight on a mild stimulus like that of violet perfume. Such a stimulus is less likely to set up a reaction directly in the sensitive tissues of the nose.)

The sensitiveness of the rat at this age to taste stimuli was also tested by Small. Warm milk, sugar solution, and a strong salt solution were used. These solutions were applied to the lips of the rat with a fine camel's hair brush. In each case the rats squeaked and wiped at the offending substance with the forepaw. The movements were brushing and pushing with the forepaws, averting the head, and movements of the whole body.

In the case of the strong salt solution there was a violent reaction, accompanied by the voiding of urine. Since all the reactions of the rats toward these taste solutions tend to a removal of the substance, Small draws the conclusion that all tastes are at first unpleasant. In the opinion of the writer this is not a valid conclusion, since the rat does not reject the mother's milk. The manner of applying the stimulus was perhaps the cause of the similarity of the reaction in each case. Again, Small tells us nothing about the temperature of the taste solutions; if it was far different from that of the mother's milk, it would very likely call forth reactions expressive of unpleasantness.

The rats at birth are very sensitive to atmospheric changes due to their defective heat regulation. At this age the rats possess a poorly developed temperature sense, responding only to very warm and very cold stimuli. They are sensitive to pain and respond to slight pinching with squeaks and struggles. The rats are, at this age, insensitive to slight pressure, except upon the tip of the nose, which is very sensitive.

While the experiments of Small are limited in number, and his deductions in one or two places are, in the writer's opinion, not quite conclusive, still one can see that at birth (and during the first twenty-four hours after birth) the rat is not only capable

of making many co-ordinated movements, but is also capable of receiving sense impressions.

There must be, too, some pathway between sensory and motor nerves, because the rat moves when his tail is pinched, sucks when the stimulus of the mother's teats touches his mouth, scratches his nose with the forepaw when he smells something unpleasant.

No medullated fibers are present in either the peripheral or the central nervous systems of the rat at this age. At two days, it will be remembered, we found a few medullated fibers in the ventral funiculus and in the ventral roots, but not until the third day are medullated fibers found in the dorsal funiculi and in the dorsal roots.

Granting now (and the evidence seems conclusive) that we have motor responses to sensory stimuli at birth, we must admit a pathway from skin to muscle. Such a pathway involves peripheral sensory neurones, central neurones, and finally motor neurones. During the first few days, at least, impulses must travel over the unmedullated axis cylinders of all these neurones.

Co-ordination in the movements mentioned above grows rapidly better. At eight days (to abstract from Small's *Notes* again) the rats are able to crawl vigorously and, when crawling, to show some selection of path by sniffing and going in different directions. "Two crawled to the edge of the table, but stopped and then crawled away. Another one got too near, lost his balance, and fell over. Another went to the edge and remained there with his head just over. This looks like a sensing of danger." Sensitivity for smell, taste, and dermal stimuli has increased rapidly since the first day.

If we turn now to the description of the medullation process at this age, we find that the dorsal and ventral nerve roots contain many medullated fibers, but the axis cylinders of the central neurones within the gray matter of the cord are almost wholly unmedullated.

Whether or not at eight days the cortex is necessary for the responses which the rats make to the various stimuli may be a question. (If the rats were really smelling out a path, it would

of course be necessary.) But, assuming that the cortex is not involved in these movements, we still have to account for the neural pathway in the lower centers over which these impulses can travel.

Granting that the fibers carrying the impulses from a given sensory area are all medullated, and granting that the motor fibers which go to the corresponding muscles in any particular case are also medullated, if nevertheless medullation is lacking in some or all of the pathways within the central nervous system, then, so far as the physiological reaction taken as a whole is concerned, we have function without medullation.

III. ACTIVITIES OF THE RAT FROM TEN TO TWENTY-FOUR DAYS OF AGE CORRELATED WITH THE INCREASE IN MEDULLATION DURING THAT PERIOD.

Turning to the writer's study of the activities of the rat at ten to thirteen days,[1] we find that it was there shown that during this period the rat is capable of forming and retaining definite associations.

The solving of the problems given to the rats at the above ages would require the use of the olfactory tract (probably at thirteen days the auditory tract was also involved), some secondary tract to the cortex, the cortex itself, the pyramidal tract, and of course the peripheral nerves.

If we examine the medullation process at this age, we find that the olfactory tract is entirely unmedullated, that a secondary medullated tract to the cortex does not exist, that the cortex is entirely unmedullated, and that the pyramidal tract contains but few medullated fibers.

From fourteen to twenty-four days we had a development on the psychical side not paralleled by a like increase in the development of medullation. From thirteen to seventeen days we found that the rats were able to return to the mother over a very complicated path. From seventeen to twenty-four days the rats could solve the "standard problems." Finally at about twenty-

[1] Part I, pp. 62 and 78, heading entitled, "The Early Stages of Memory."

four days we found that the rat could solve a problem which the adult could solve only after thirty or forty trials. At approximately twenty-four days we felt justified in saying that the rat is psychically mature, meaning by that, as we have before explained, that at twenty-four days of age the rat has the capacity to learn anything (so far as our experiments in the laboratory went) that a rat at maturity can learn.

What is the condition of the medullation process at twenty-four days? In Part II we endeavored to show that at twenty-four days the rat has only about one-half of its dorsal root fibers and two-thirds of its ventral root fibers medullated; that the number of medullated fibers in the white fasciculi of the cord is far less at this age than at maturity (how much less we are at present unable to say); that the number of medullated fibers within the gray matter of the cord is not as great as at maturity; that the medullation in the cerebellum at twenty-four days, compared with that found there at maturity, is poorly advanced; the laminæ are not closely packed with medullated fibers at twenty-four days of age, nor at that age do many such fibers leave the laminæ to project into the granular layer. A count was made of the medullated fibers projecting into the granular layer within a strip 150 micra wide (the locality chosen was at the termination of lamina D) at twenty-four days and at maturity. At maturity we find in the given area twenty-four medullated fibers; at twenty-four days in the corresponding area we find eight.

But it is when we compare the cross-section of the cerebrum at the two ages that we find the greatest differences in the development of medullation. At twenty-four days in the corpus callosum medullated fibers are almost wholly lacking. The same is true of the anterior commissura. Again, the number of medullated fibers raying out into the cortex at twenty-four days is not at all comparable to the number found there at maturity. As in the cerebellum, a count was made of the number of medullated fibers raying out toward the surface of the cortex within a strip 150 micra wide at twenty-four days and at maturity. At maturity we find in this strip fifty medullated fibers; at twenty-

four days in the corresponding strip, ten fibers. (The locality chosen was in the fibers radiating from the sharp angle of the external capsule near the fibræ longitudinales dorsales.)

Even this great disparity in the number of medullated fibers projecting into the cerebral and cerebellar cortices is not a perfect index of the immaturity of the medullation process in these regions at twenty-four days, because a given area in the cerebellar cortex will increase from this age to maturity 36.5 per cent., and a given area in the cerebrum will increase after twenty-four days 21.6 per cent. Then again at twenty-four days the fibers are lightly stained, just visible under a high-power lens, while at maturity they are stained almost black. At twenty-four days these fibers in the cortex of the cerebrum possess no medullated collaterals, consequently at that age we have no dense network of cross fibers. At maturity this network is most complex and by far the most beautiful sight in the whole nervous system.

It seems to me that we now have the answer to the two main neuro-physiological questions raised at the beginning of this work: (1) medullated fibers in the cortex of the rat are not a *conditio sine qua non* of the rat's forming and retaining definite associations; (2) the complexity of the psychical life increases much more rapidly than does the medullation process in the cortex, psychical maturity being reached when approximately only one-fifth of the total number of fibers in the cortex are medullated.

But the following questions at once arise: (1) Is there a great number of unmedullated axis cylinders present at twenty-four days? (2) Do new fibers grow out from cell bodies after twenty-four days? (3) Are we to attach no significance to the enormous increase in the number of medullated fibers after twenty-four days? (4) Should we grant that there is no increase in the psychical life of the rat after twenty-four days?

1. In the opinion of the writer, the great majority of the medullated fibers at maturity are present in the rat at twenty-four days of age as unmedullated axis cylinders. In the corpus callosum, in the cortex, and elsewhere multitudes of fibers appear bare of any medullary sheath.

2. That new fibers grow out from cell bodies after twenty-four days the writer would not attempt to deny. Mr. Ranson, working in this laboratory (whose report is yet unpublished), has definitely proven this. But, compared with the increase in the number that become medullated after twenty-four days, the addition of new fibers is small.

3. The answer to the question concerning the significance to be attached to the enormous increase in the number of medullated fibers after twenty-four days is bound up with the answer to the question: *Was überhaupt* is the significance of medullation? When this latter question is answered, our own will be an easy one. What we are opposing is the general acceptance of the proposition that the increase in the complexity of the psychical life runs parallel with the increase in the number of the medullated fibers in the cortex.

4. We readily grant that there is an increase in the complexity of the psychical life of the rat after twenty-four days. The rat after twenty-four days is constantly adding to its stock of associations. Certainly, if the rats were allowed to run wild and compelled to seek their own food, we should in all probability find that the old rat, owing to his larger stock of associations, would be able in numerous instances to obtain food more quickly than a rat twenty-four days of age. But put the two rats in a totally new situation, give them some problem, with the satisfaction of an appetite as the reward for overcoming the difficulties involved in it, and the indications are that the young rat will be master of the situation even more quickly than the adult.

IV. THE BEARING OF THIS STUDY UPON THE CORRELATIONS MADE BY FLECHSIG.

It seems to the writer that the present investigation has some bearing upon the wholesale correlations that Flechsig makes between the medullation in the centers of association (particularly in the frontal regions) and the increasing complexity of our human psychical life. Flechsig, it will be remembered, holds that not until after the second month of post-natal life can intelligence begin to play any rôle in the life of the child. (This state-

ment is made in spite of the fact that Preyer and others have many indications of the intellectual awakening long before this age is reached.) It is at this period that medullation begins in the centers of association. This process of medullation continues in these regions until late in life, and as the process continues the psychical life increases commensurately in complexity.

If any analogy can be entertained between man and the rat, it seems to me that we need not make any such correlations as Flechsig. Why not assume that at some point in the development of the nervous system of man there exists a period comparable to the twenty-four-day period in the rat. At this age the individual will be teachable; he will not have the ready ability to handle difficult situations that his father has; the psychical life of the child lacks the rich and varied experiences that have come to the parent with age. Corresponding to this stage in the psychical life we should have on the neural side a condition in the medullation process similar to the one found in the rat at twenty-four days: certain nerve tracts, which must be the pathway of nervous impulses, would still be unmedullated. Why one tract should become medullated sooner than another we can at present answer in the case of the man no better than in the case of the rat.

FIG. 4.—Cervical. Six Days.

FIG. 7.—Cervical. Thirteen Days.

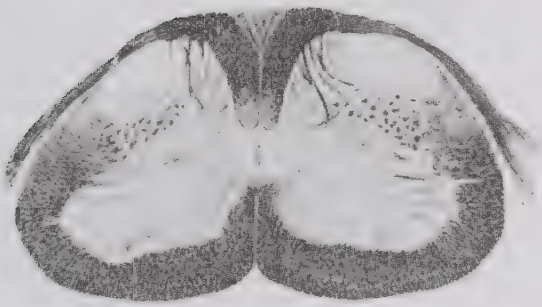

FIG. 10.—Cervical. Twenty Days.

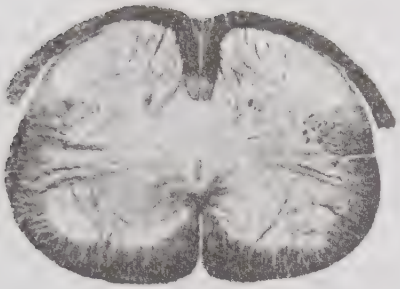

FIG. 13.—Lumbar. Twenty-four Days.

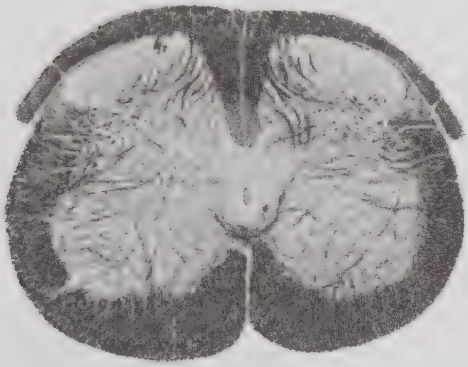

FIG. 16.—Lumbar. Thirty-five Days.

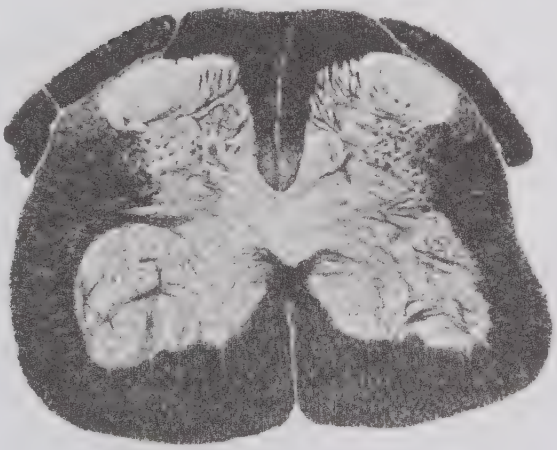

FIG. 19.—Lumbar. Adult.

FIG. 26.—Cerebrum. Thirty-five Days.

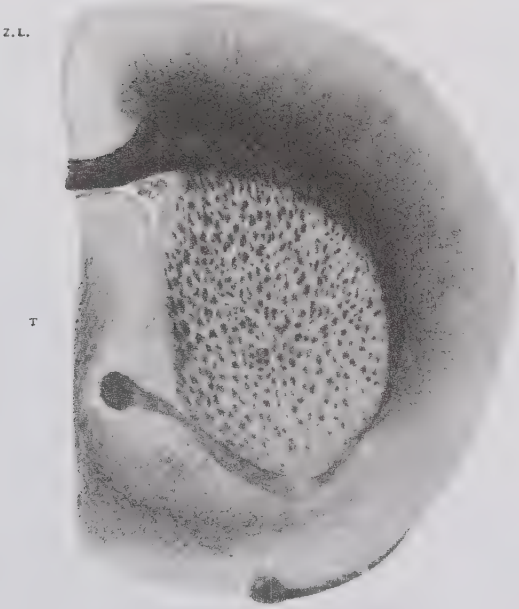

FIG. 27.—Cerebrum. Adult.

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